Decentralised Wastewater Treatment Systems (DEWATS) and Sanitation in Developing Countries



A Practical Guide

Editors: Andreas Ulrich, Stefan Reuter
and Bernd Gutterer

Authors: Bernd Gutterer, Ludwig Sasse,
Thilo Panzerbieter and Thorsten Reckerzügel

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WEDC is one of the world's leading education and research institutes for for developing knowledge and capacity in water and sanitation for low- and middle-income countries. Education and training programmes at postgraduate-level include Water and Waste Engineering and Water and Enviromental Management.

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This publication is a collective effort. Since the early 1990s BORDA has collaborated with a multitude of individuals and institutions throughout Europe and Asia to develop the DEWATS approach. The first DEWATS Handbook was published by Ludwig Sasse in 1998. It served as an instruction manual focusing on the technical design. A wealth of experience in demand-oriented technology adaptation and dissemination has evolved since then, including public health and community-based sanitation. This book presents the collaborative efforts made by a wide range of professionals from local and central authorities, from private businesses and international donors, NGOs, community-based organisations and academia. Therefore, this publication could not have been realised without the generous contribution of the many individuals and organisations who shared their experience and expertise.

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1 Introduction

Water is a key feature of public concern worldwide. Inappropriate use and poor management of water resources have an increasingly negative effect on economic growth, on social welfare and on the world's eco-systems.

For a long time the need for efficient wastewater treatment was ignored by many public authorities. As a result the performance of existing treatment technologies and the conditions of sanitation facilities are rather poor. At many locations the sewage is just drained to surface or ground waters without any adequate handling at many locations.

In the last few years decision makers, planners, engineers and stakeholders civil society launched multiple initiatives to meet the challenge facing many developing countries do face: How to ensure a good performance and a high coverage of wastewater treatment under rather difficult conditions with financial constraints and limited human and institutional capacities?

In the 1990s an international network of agencies and NGOs drew conclusions about the deficiencies of existing infrastructure development and developed the so-called "DEWATS approach." DEWATS is designed to be an element of comprehensive wastewater strategies: not only the technical requirements for the efficient treatment of wastewater at a given location, but the specific socio-economic conditions are also taken into consideration.

By its principles of "reliability" and "longevity", the permanent and continuous treatment of wastewater flows from 1-1000 m^3 per day, from both domestic and industrial sources should be guaranteed. With its flexibility, efficiency and cost effectiveness, these systems are planned to be complementary to centralised wastewater treatment-technology and to strategies reducing the overall generation of wastewater.

The international discussion about the conservation of water resources and more target-oriented poverty-alleviation strategies creates a favourable environment for new sanitation approaches and innovative wastewater treatment solutions.
In many countries a rapidly upcoming market for DEWATS and a demand for efficient Community-based Sanitation (CBS) can be observed.

Based on the experiences and "good practices" of numerous programmes and projects, this book aims to present the most important features for successful DEWATS dissemination:

- Driving forces and decision parameters for innovative wastewater and sanitation strategies.
- Options for a comprehensive technology choice
- Planning instruments for wastewater treatment and sanitation mapping
- Presentation of the DEWATS approach and good practices in DEWATS
- Basic knowledge about the process of wastewater treatment
- The technical components of DEWATS
- Design principles for DEWATS
- Guidelines for programme development and implementation of DEWATS based Community-based Sanitation programmes.

Since wastewater treatment and sanitation, with all its implications, is such a complex subject, the content focuses on providing a basic knowledge that is relevant for DEWATS dissemination. As a practical guideline it should support decision making, planning and implementation activities. For very specific questions, additional literature can be consulted. A selection of books and articles can be found in the appendix.

Andreas Ulrich

Stefan Reuter

Dr. Bernd Gutterer

Bremen/Berlin February 2009

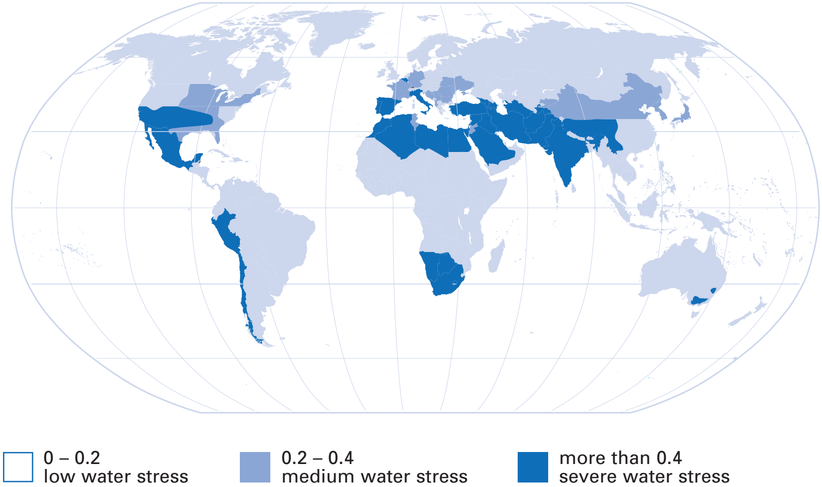
2 Towards comprehensive wastewater and sanitation strategies

2.1 World water resources under threat

1 Water stress occurs when the demand for water exceeds the available amount during a certain period or when poor quality restricts its use. Water stress causes deterioration of fresh water resources in terms of quantity (aquifer over-exploitation, dry rivers, etc.) and quality (eutrophication, organic matter pollution, saline intrusion, etc.). Source: European Environment Agency, EEA glossary, 2006

Water is the essential basis for all forms of life. Water is of utmost importance for human health and dignity. Water is crucial for sustainable social and economic development. However, world water resources are under threat. In the past 250 years the world has seen a tremendous increase both in population and economic activitiess. This development process has resulted in extensive social transformation and a rapidly increasing demand for natural resources. Urbanisation, industrial development and the extension of agricultural production have a significant impact on the quantity and quality of water resources. Overexploitation of water bodies and deterioration of water quality are global trends.

Today one-third of the world's population lives in countries suffering from moderate to high water stress.[1] Since the mid-1990s, some 80 countries, representing 40 per cent of the world's population, have been suffering from serious water shortages in urban and rural areas – in a lot of cases, the result of the socio-economic development over the recent decades.



Picture 2_1: Water stress in regions around megacities Source: UNESCO, WWAP, 2003, World Water Commission on Water, 1997

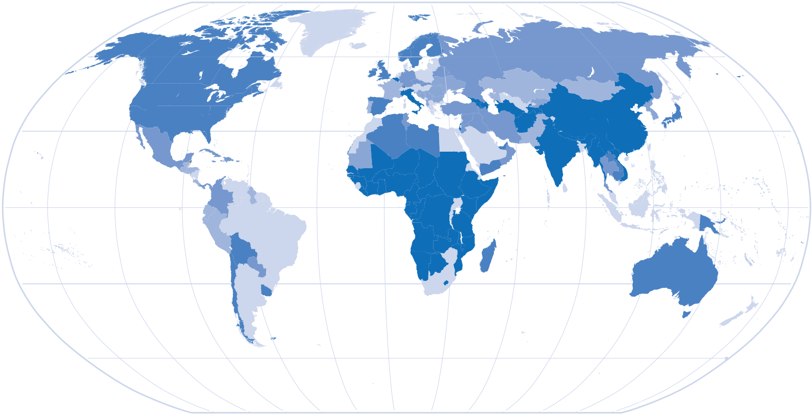
The increasing demand for freshwater sources and rapidly changing production and consumption patterns are directly linked with the pollution of ground and surface waters. "More than half of the world's major rivers are seriously depleted and polluted, degrading and poisoning the surrounding ecosystems, threatening the health and livelihoods of those who depend on them.[2]"

2 World Commission on Water 1997

Picture 2_2:
More than half of the world's major rivers are seriously depleted and polluted

Although the threat to water resources is not only a phenomenon in developing countries, it is particularly the world's poor that are most affected: worldwide, 1.1 billion people still lack access to safe drinking water and 2.6 billion lack access to adequate sanitation. Estimates indicate that approximately half the population of the developing world is exposed to polluted water resources, which increase disease incidence; most of these people live in Africa and Asia.[3]

3 UNICEF/WHO, 2004



Picture 2_3:
Half the developing world are still without improved sanitation; Source: UNICEF/WHO, 2004

Percentage of population using improved sanitation

Less than 50% | 50% – 75% | 76% – 90% | 91% – 100% | Insufficient date

2 Towards comprehensive wastewater and sanitation strategies

The challenges ahead are obvious: the urban population of the less-developed world is expected to nearly double in size between 2000 and 2030 from justunder 2 billion to nearly 4 billion people, with the greatest urban growth occurring in Asia. By that time, 58 per cent of the world's population will live in urban or semi-urban areas. Pessimistic scenarios forecast that nearly 7 billion people in 60 countries will live in water-scarcity by 2050, whereas even rather optimistic projections estimate that just under 2 billion people in 48 countries will be affected.

Over the last 30 years, a multitude of national and multi-national initiatives have addressed the emerging water crisis. In 1980 the International Water Supply and Sanitation Decade (IWSSD) was launched. At the so-called Rio Conference in 1992 "water" was identified as one of the key elements for sustainable development:

> "The general objective is to make certain that adequate supplies of water of good quality are maintained for the entire population of this planet, while preserving the hydrological, biological and chemical functions of ecosystems, adapting human activities within the capacity limits of nature and combating vectors of water-related diseases."[4]

4 Agenda 21, Chapter 18

In September 2000, 189 UN member states adopted the so-called Millennium Development Goals, setting well-defined targets for the world's most pressing development issues:

> "Halve, by 2015, the proportion of people without sustainable access to safe drinking water and basic sanitation."

In order to meet this sanitation target, anadditional 1 billion urban dwellers and almost 900 million people in rural communities have to be served with adequate facilities by 2015; this equates to approximately half a million extra people to be serviced each day.

2.2 The protection of water resources – achievements and challenges

A number of encouraging results have been achieved by various initiatives launched on very different levels since the Eighties. While in 1990, only 77 per cent of the world's population used improved drinking-water sources, in 2002 a global coverage of 83 per cent was achieved. The deterioration of water supply infrastructure in many developing countries – the per capita water-supplies had decreased by a third between 1970 and 1990 – was stopped in most places.

In the few years, governments have developed more efficient approaches to halt the increasingly urgent water crisis:

- More efficient legal frameworks are being developed and, in many places, law enforcement has been improved
- Water policy is increasingly recognised as a cross-cutting task for socio-economic development
- Water resources are more comprehensively assessed through the application of new planning methods and technologies
- The conservation and sustainable use of water for food production and other economic activities receives more emphasis
- Institutional and human capacity to assess and manage water resources are being created

Nonetheless, considering the number of people who are still without a safe water supply, the tasks required to meet the Millennium Development Goals are enormous.

In the fields of sanitation and waste-water treatment, the challenges are even greater. Although global sanitation coverage increased from 49 per cent in 1990 to 58 per cent in 2002, 2.6 billion humans (!!) still live without improved sanitation.

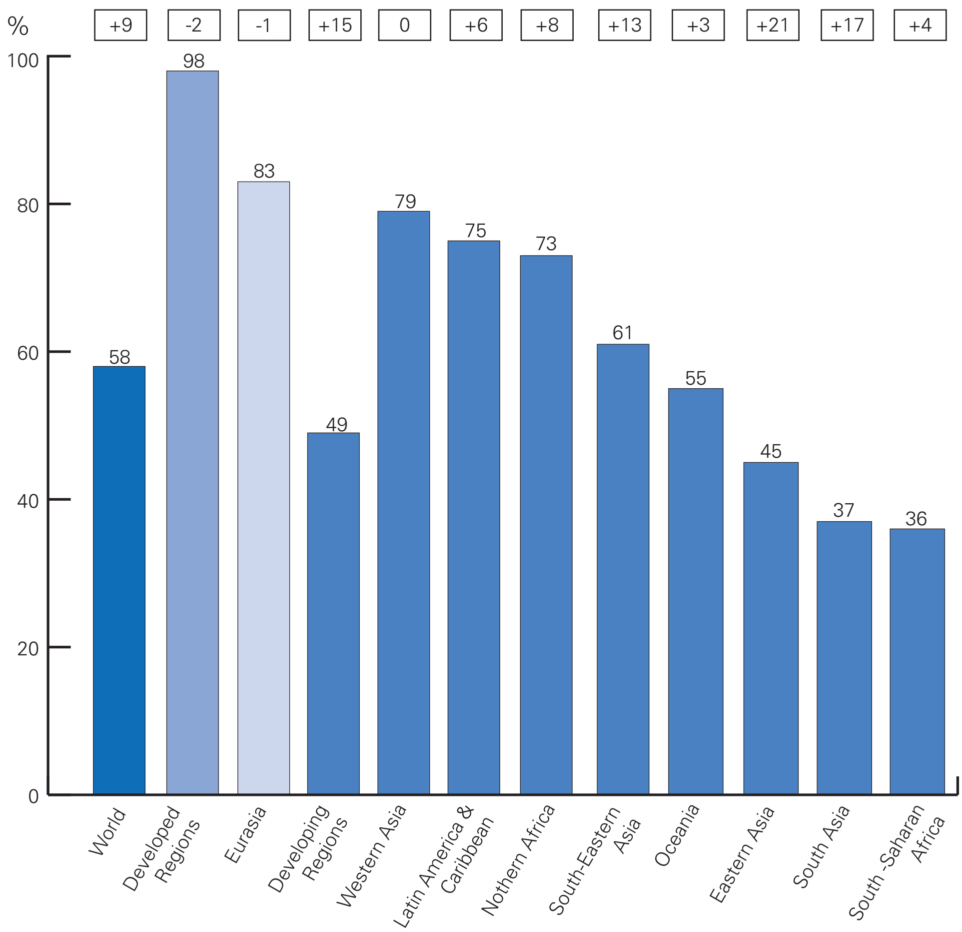
Picture 2_4:
Water supply was improved at many locations

In India and China alone, nearly 1.5 billion people live without adequate facilities; in Africa, coverage extends to only 36 per cent of the population, and in Latin America and the Caribbean about 137 million people have no access – a critical situation.

The impact of poor sanitation and water pollution is obvious:

> "Inadequate water supply and poor sanitation cause more than 500,000 infant deaths a year as well as a huge burden of illness and disability in the (Asian) region. Some 8–9 per cent of the total Disability Adjusted Life Years (DALYs) are due to diseases related to inadequate water supply and poor sanitation in India and other countries. Cholera is prevalent in many countries, particularly those where sanitation facilities are poor such as Afghanistan, China and India."[5]

5 UNEP: Global Environment Outlook 3. DALYs = Disability Adjusted Life Years – the sum of years of potential life lost due to premature mortality and the years of productive life lost due to disability (Def. WHO).



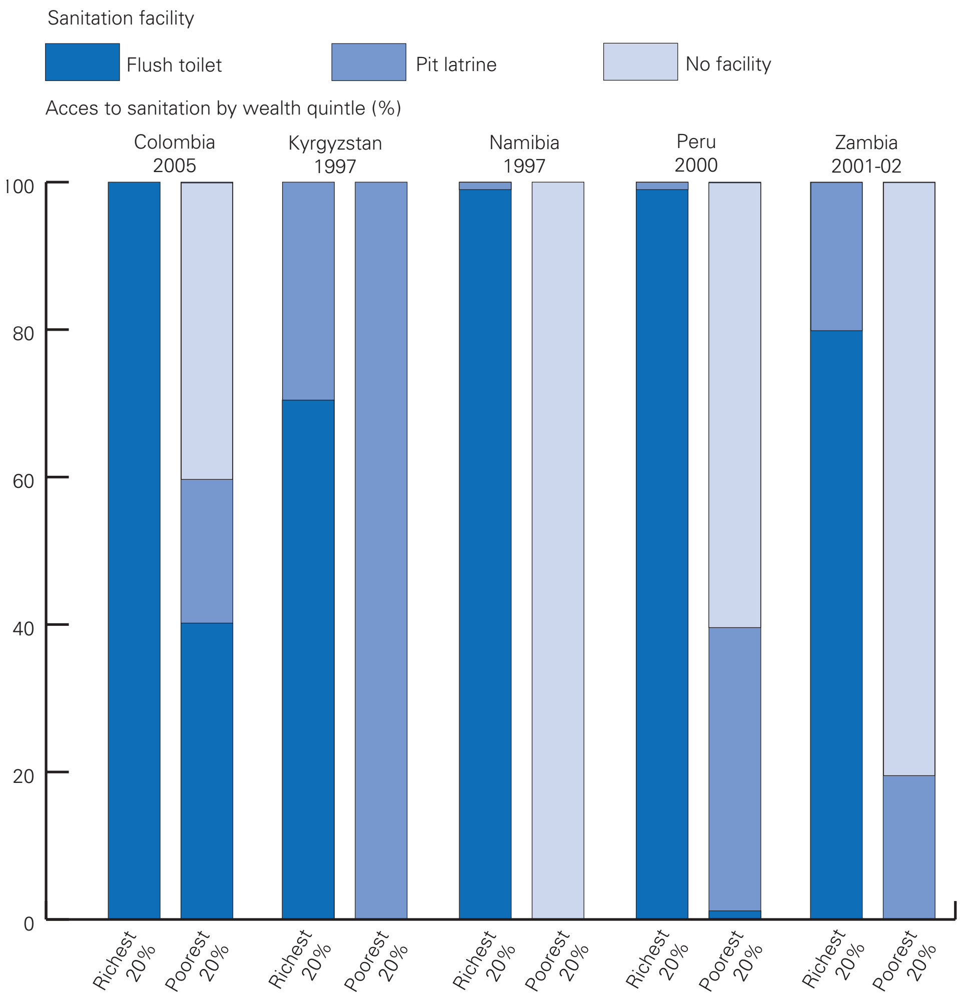
Picture 2_5: Sanitation coverage lowest in sub-Saharan Africa and South Asia. UNICEF/WHO, 2004

It is the poor sections of these populations who are most affected by the increase of water-borne diseases. Many live in a vicious cycle of unhealthy living conditions, faecal-oral disease, illness and poverty.

The statistics on water borne disease underline the scale of the challenges that lie ahead:

- 4 billion cases of diarrhoea and 2.2 million deaths annually
- intestinal worms infect 10 per cent of the population of the developing world
- 6 million are blind from trachoma
- 200 million people are affected with schistosomiasis[6]

6 WHO/UNICEF, 2000 UNDP, 2006



Picture 2_6: Access to sanitation by wealth quintile in selected countries; Source: UNDP: Human Development Report 2006 Source: UNDP, 2006

2.3 A short assessment of the sanitation and wastewater sectors in developing countries

Poor sanitation should be perceived as an element of an overall process of inadequate use of water. Poorly treated wastewater has negative effects on public health. Furthermore, its high oxygen demand damages eco-systems, causing eutrophication in open water bodies, due to excessive nutrient supply; aquatic life is destroyed. Toxic substances also reach the groundwater, which approximately 2 billion people – about one-third of the world's population – depend on for water supply.

The three main sources of water pollution in developing countries are domestic, industrial and agricultural. The volume and characteristics of each type of wastewater differ by source and location (urban, rural). In total, domestic wastewater generally contributes the most organic load. In the Philippines, for instance, municipal (domestic) wastewater generates 48% of the national BOD (biochemical oxygen demand) (Industry 15%, Agriculture 37%); in Thailand, municipal wastewater generates about 54% of the total BOD.[7]

Water pollution from domestic, agricultural and industrial sectors results in tremendous public and private economic losses. Calculations of external costs indicate that in China about 2.6%, in Mexico about 3.3%, in India about 4.53%, in Eastern Europe up to 5% and in industrial countries between one and two per cent of the GDP is lost due to water pollution.[8] The World Bank estimates the annual losses to the Philippines' national economy to be about PhP 67 billion (US$ 1.3 billion); this can be broken down into PhP 3 billion for the health sector, PhP 17 billion for fishery production, and PhP 47 for tourism.[9] In Indonesia, economic losses are conservatively estimated at US$ 4.7 billion per year, which is roughly equivalent to US$ 12 per household per month.[10]

7 World Bank, 2005

8 CERNA, 2003

9 World Bank, Philippines Environment Monitor, 2003

10 World Bank, Indonesia Environment Monitor, 2003

Comprehensive sanitation strategies must therefore protect public health and the environment; they should include the collection, the treatment, the disposal, the recycling and, especially, the avoidance of waste. Wastewater strategies must address an array of different wastes:

- Human excreta (urine + faeces = blackwater)
- Household wastewater (shower + washwater = greywater)
- Stormwater
- Waste from industrial production
- Hazardous waste, as from hospitals
- Solid waste

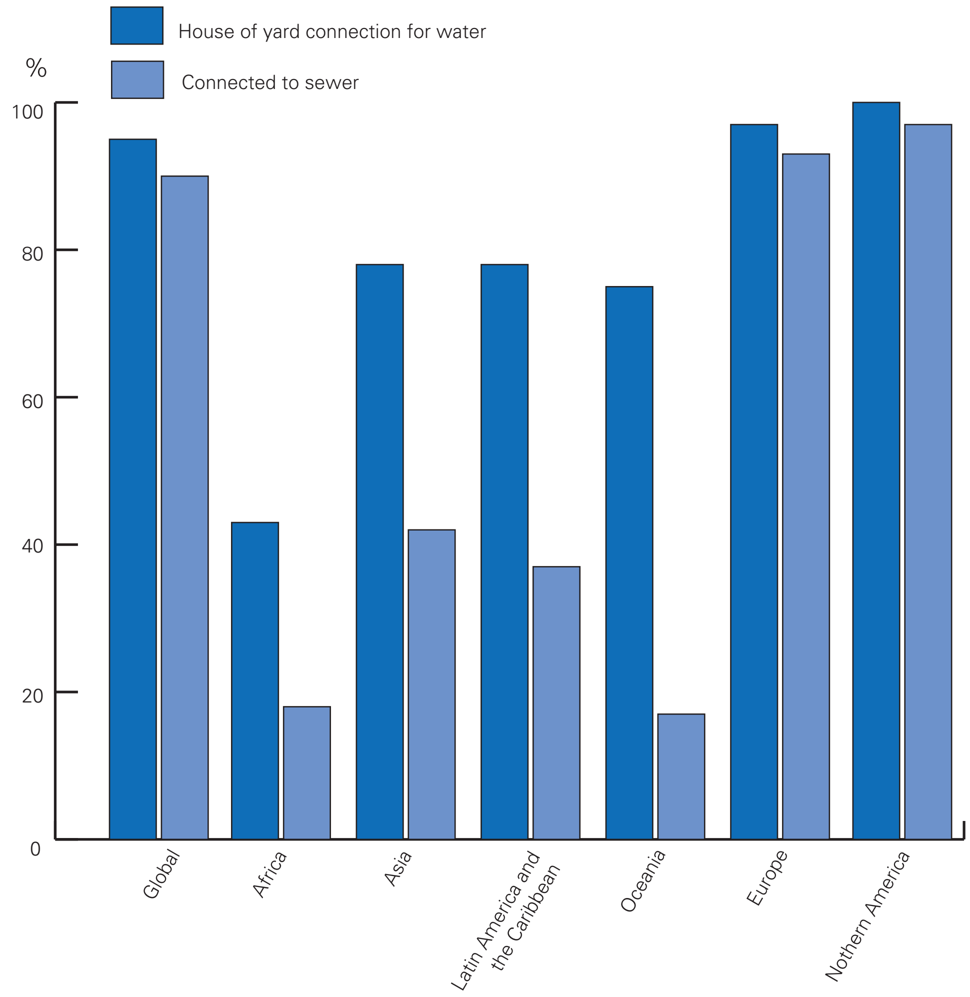
Picture 2_7: Water pollution causes tremendous public and private economic losses

Picture 2_8: Open drainage of untreated wastewater is a prime source of serious disease

For a long time, wastewater treatment systems in the "developed world" were seen as the ideal solution, which should also be applied in the "developing world". Wastewater treatment was perceived as a highly technical engineering task; flush toilets were used to transport the human excreta through big sewer systems to rather technically sophisticated wastewater-treatment plants.

However, a study carried out in 116 cities worldwide indicated a low connection of households to sewers in Africa, Asia, Latin America, the Caribbean and Oceania. Surveys show the rather weak efficiency of centralised wastewater-treatment systems.[11]

11 WWDR/WHO/ UNICEF, 2003



Picture 2_9: Global water supply and sanitation Assessment, 2000 report; Source: WWDR, WHO/UNICEF

12 Central Pollution Control Board, New Delhi. Class I cities are urban agglomerations with a population of 100,000 or more. Class II (50,000 to 99,999), Class III (20,000 to 49,999), Class IV (10,000 to 19,999), Class V (5,000 to 9,999). 1 MLD = 1 million litres per day.

Most of the sewage in developing countries is discharged to nature without adequate treatment. An assessment published by the Central Pollution Control Board in New Delhi indicates that only a small quantity of sewage is leed to treatment plants in India. While in so-called "Class 1 cities" 33% of the collected and 24% of the total wastewater is treated, only 5.6% of the collected and 3.7% of the total wastewater is treated in smaller "Class II cities".[12]

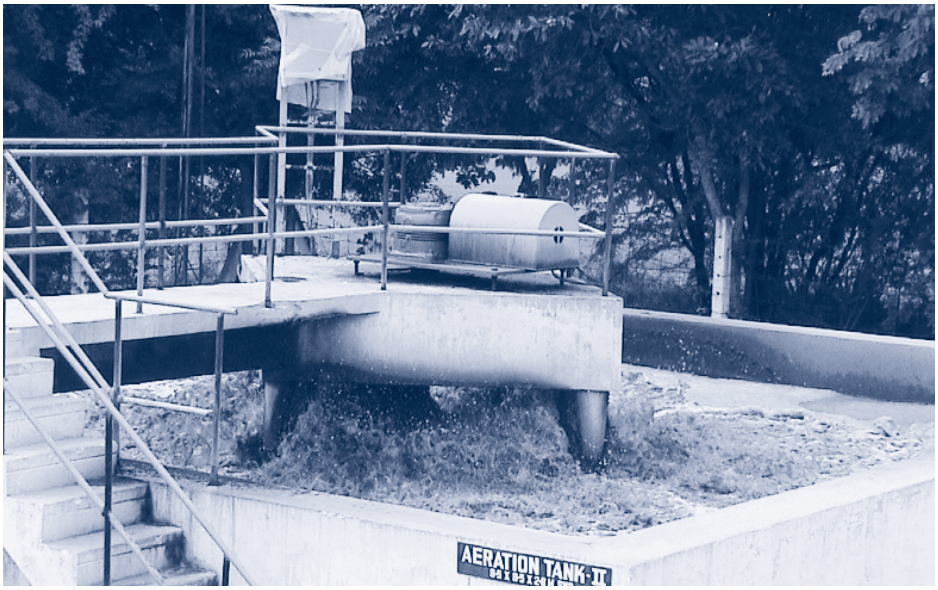
Type	Number of cities/ towns	wastewater generated (MLD)	wastewater collected		wastewater treated		
			MLD	% (of generated)	MLD	% (of generated)	% (of total)
Class I Cities	299	16662.5	11938.2	72	4037.2	33.8	24.0
Class II Towns	345	1649.6	1090.3	66	61.5	5.6	3.7
Total	644	18312.1	13028.5	71	4098.7	31.5	22.4

Table 1:
Central pollution control board Delhi

These figures correlate with experiences made in other countries. In the Philippines, only 7% of the total population is connected to sewers and more than 90% of the sewage generated in the Philippines is not disposed of or treated in an environmentally acceptable manner. Figures from Latin America and the Caribbean show that only 14% of the effluent is treated.[13]

13 Central Pollution Control Board, Dehli, Global Water Partnership, 2004

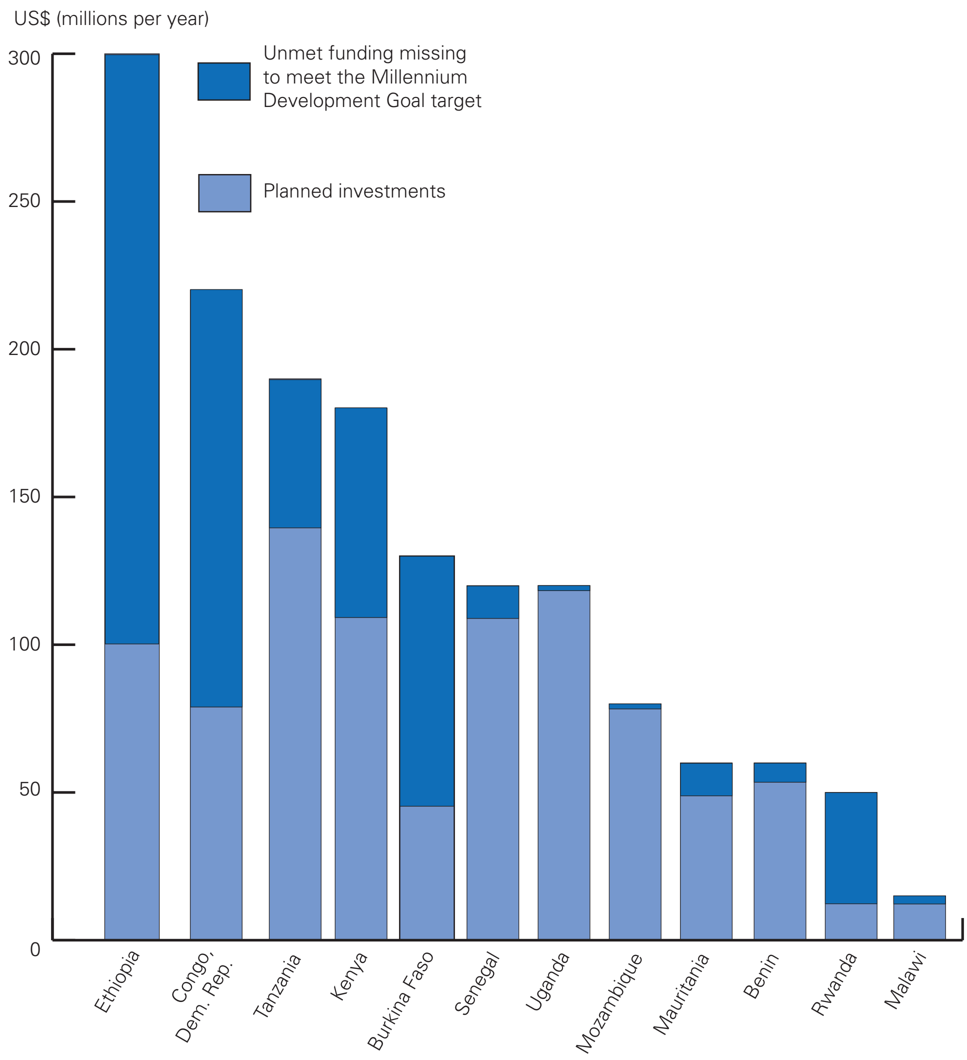
A closer look at the performance of existing wastewater-treatment systems reveals further reasons for the rapid deterioration of coastal waters and the dead watersbodies found in many countries. Technical and maintenance problems result in low treatment efficiency and a discharge of still highly contaminated effluent.



Picture 2_10:
Power cuts and maintenance problems are frequently encountered at conventional, decentralised wastewater-treatment units

Poor performance is also observed in many so-called decentralised wastewater-treatment solutions, such as the:

- rotating disk reactor
- the trickling filter
- the activated sludge process
- the fluidised bed reactor and
- the sequencing batch reactor



Picture 2_12: The gap between planned investments and funding required to meet Millennium Development Goal in Sanitation; Source: UNDP, Human Development Report 2006

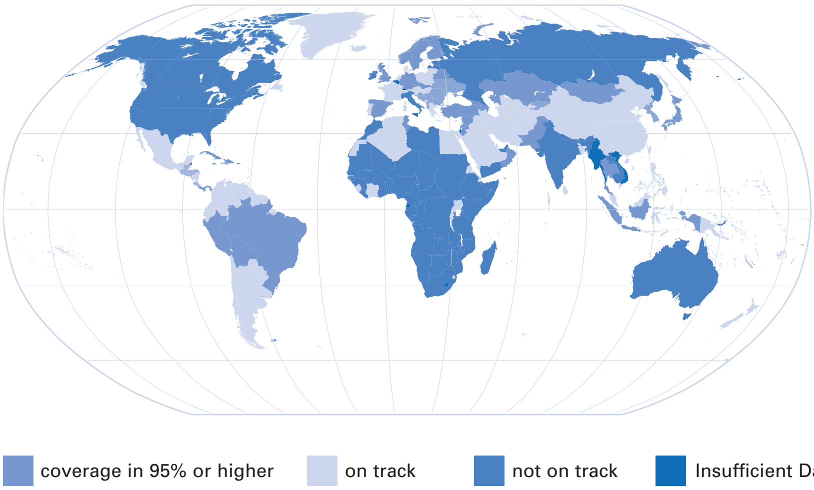
WHO estimates that meeting the target of the United Nations Millennium Development Goal for sanitation in urban areas requires annual funds of approximately US$100 billion.

Due to the technological, institutional and organisational requirements, such complex wastewater projects are unthinkable in many parts of the world. The enormous required funds area of available, and the high water demand for flushing toilets (30–50% of domestic water consumption) further increases water stress, particularly in arid and semi-arid regions.

The desperate need for the establishment and implementation of efficient sanitation programmes becomes even more apparent on viewing the slow progress of sanitation programmes worldwide between 1990 and 2002. The term "sanitation" frequently only refers to the collection, removal or disposal of human excreta; as well as the connection to a public sewer system, "improved sanitation" can include other technical solutions, like:

- septic-tank systems
- pour-flush latrines
- simple pit latrines, and
- ventilated improved pit latrine

Although these technologies are fairly simple to implement and maintain, progress in implementing them remains rather slow in many countries.



Picture 2_13: Progress in sanitation, 1990-2002 Source: UNICEF/WHO, 2004

2.4 Signs of change – Elements of efficient and sustainable sanitation programmes

The reasons for slow progress in the sanitation sector are manifold. Performance both the policy and implementation levels has been unquestionably weak in the past, resulting in unclear, contradictory or non-existent sanitation policies.

Typical political and administrative deficiencies are:
- lack of political will
- low prestige and recognition of the sector
- poor policy at all levels
- weak institutional framework
- inadequate and poorly used resources
- inappropriate approaches
- failure to recognize defects of current excreta-management systems
- neglect of consumer preferences
- ineffective promotion and low public awareness
- women and children last[14]

14 WHO, 1998

Within projects, considered at the implementation level, the following deficiencies have been observed:
- isolated character of the activities
- poor coordination between initiatives
- insufficient construction quality
- poor adaptation of designs to local conditions
- hardware-driven approaches
- insufficient involvement of users and other relevant local and regional stakeholders for implementation (top-down approach)

Recently, the situation has begun to change; national and international discussions are beginning to show results. In 2001, for instance, the Government of the Republic of South Africa published a white paper on "Basic Household Sanitation". At that time, about 18 million citizens had no access to adequate sanitation. Within the strategic paper, the government underlined its constitutional responsibility to ensure sanitation access to all South Africans.

The purpose of the paper was to:

- spell out government policies on sanitation
- provide a basis for the formulation of local, provincial and national sanitation-improvement strategies
- provide a framework for municipal sanitation programmes
- ensure that sanitation-improvement programmes are adequately funded, and
- install mechanisms for monitoring the implementation of the policy and sanitation-improvement programmes[15]

15 Government of South Africa, 2001

Picture 2_14: On the outskirts of major South African cities, people face poor sanitation

In 2002, the Government of Indonesia published a similar document, addressing the country's requirements for more efficient and sustainable implementation of safe water supply and sanitation. Within the paper, the government drew conclusions from problems faced in earlier programmes within the Water Supply and Environmental Sanitation (WSES) sector – and defined essential principles for future programmes:

- The role of all stakeholders involved in a programme must be clearly defined and their commitment ensured
- Programmes must meet of the demand communitys
- Participatory management – involving all segments of the user community, especially women – is essential for successful long-term operation and maintenance
- The approach for environmental sanitation should be distinguished from that for clean water
- High quality of services is essential for meeting the expectations of the users and ensuring their willingness to pay for the services[16]

16 Ministry of Settlement and Regional Infrastructure, Ministry of Health, Ministry of Home Affairs, Ministry of Finance, National Development Planning Agency/ Bappenas, 2002

2.5 Towards service orientation – the conceptual framework of basic needs sanitation programmes

Although the documents discussed in the previous section were developed-in a specific country context, both papers reflect ongoing, worldwide discussions concerning the development and implementation of successful sanitation programmes. Based on a broad range of position papers and experiences, the crucial importance of the definition of roles and tasks of different stakeholders involved in the process are outlined in the following:

- The elaboration of an efficient, adequate legal and regularity framework and the provision of budget lines are basic tasks of the central and regional governments, respectively
- Since sanitation programmes are far more than just hardware dissemination, the definition of the procedure for the institutionalisation process within public bodies (horizontal and vertical level) must be defined within the regularit framework. Special emphasis should be given to the definition of responsibilities and co-operation between different ministries and departments (public works, environment, health, etc); as well as how they are broken down at the national and to local level
- Regional and local governments should be aware of the important role that sanitation programs play within regional integral development. Sanitation goals and corresponding timelines should be established; these should comply with national legislation, norms and standards. Regional and municipal levels should monitor and ensure efficient co-ordination between concerned public entities.
- In most cases, the provision of sanitation facilities is the responsibility of local government, which must carry on the following tasks during implementation: awareness building within communities, decision-making in close collaboration with concerned communities, developing implementation schemes, budget allocation, monitoring implementation, setting up sludge-treatment systems and ensuring sustainability of the programmes
- Sanitation schemes must be developed in close co-operation with the communities. Since hygiene starts with the awareness and sanitation practices of each individual, sanitation programmes usually fail without the active involvement of the households. Community involvement is essential for ensuring regular use, continuous maintenance and financing of the sanitation facilities

- Private-sector companies must not only deliver good-quality hardware, but also ensure long-term operation and maintenance as service providers. Public-private partnership models can ensure large-scale implementation and operation of sanitation facilities
- In many countries, non-governmental organisations (NGOs) initiate and facilitate the development and implementation of sanitation programmes. They launch awareness raising-campaigns, facilitate decision-making within communities, establish communication between communities and local governments, and even work as implementing agencies or service providers. Their roles depend on the profile and institutional competencies of each respective organisation, as well as the local conditions of the project area

Picture 2_15: Multi-stakeholder involvement is vital to successful sanitation programmes

Picture 2_16 "Demand-responsive approaches" have been developed in order to ensure the efficiency and sustainability of sanitation programmes

The concepts of "multi-stakeholder involvement" and "result-driven programme portfolio" correlate with a new perception of basic-needs infrastructural development:

- The "demand-responsive approach" should be a main feature of any sanitation programme; the users are perceived as “clients”, who express a need and create a demand for sanitation services. Since public entities and other stakeholders respond to the demand of the communities, the approach is referred to as "community-based sanitation"
- The active involvement of "users", "clients" or communities is crucial for the sustainability of the programme. "Willingness to pay" is not only a strong indicator that the community is actually interested in the programme, but also the basis for professional, long-term operation and maintenance of the sanitation system[17]

17 The demand responsive approach and the main principles of community-based sanitation are discussed in chapters 5 and 6 of this handbook

2.6 The increasing demand for efficient and reliable decentralised wastewater-treatment solutions

Sanitation programmes should be an integral part of comprehensive wastewater strategies and vice-versa. Connecting sanitation facilities to sewerage or to septic tanks alone, however, does not ensure the adequate treatment of domestic wastewater. In order to meet legal effluent standards, solutions for secondary and tertiary treatment must be found.

In recent years, improved legislation and growing public awareness have led to a rapidly growing demand for suitable wastewater solutions. Water quality and discharge standards are defined on the basis of legislation, such as the Philippines "Clean Water Act" (2002), the Vietnamese "Law on Water Resources" (1999), or the "Water Act" in India. These standards are subject to law enforcement, court cases and public debate.

Picture 2_17
Improved legislation and law enforcement are the main driving forces behind the rapidly growing demand for new wastewater treatment solutions

3 DEWATS – Sustainable treatment of wastewater at the local level

Private and public entities are faced with the following situations:

- national and regional development plans require the wastewater connection of peri-, semi-urban and rural settlements to treatment facilities, which meet discharge standards
- new housing and real estate developments do not get clearance without approved wastewater-treatment systems
- schools, hospitals, hotels and public facilities face public pressure, due to surface-water pollution
- Small and medium enterprises unable to treat wastewaters adequately are closed down by public authorities

Only a few of the households, as well as public and private entities, that require wastewater treatment can be serviced by conventional sewage and wastewater-treatment systems. The rapidly growing demand can only be met with the assistance of other technical solutions, which should ideally fulfil the following criteria:

- Suitable for very diverse local conditions and versatile in application
- Provide reliable and efficient treatment of domestic and process wastewater
- Require only short planning and implementation phases
- Moderate investment costs
- Limited requirements for operation and maintenance

It is evident that decentralised wastewater solutions, which fulfil these criteria, have to become an integral part of comprehensive wastewater strategies, complementing to other approaches.

3.1 DEWATS – a system approach to ensure efficient wastewater-treatment performance

"Decentralised Wastewater Treatment Systems" (DEWATS) were developed by an international network of organisations and experts. The approach incorporates lessons learned from the limitations of conventional centralised and decentralised wastewater-treatment systems, thereby assisting to meet the rapidly growing demand for on-site-wastewater solutions. DEWATS are characterised by the following features:

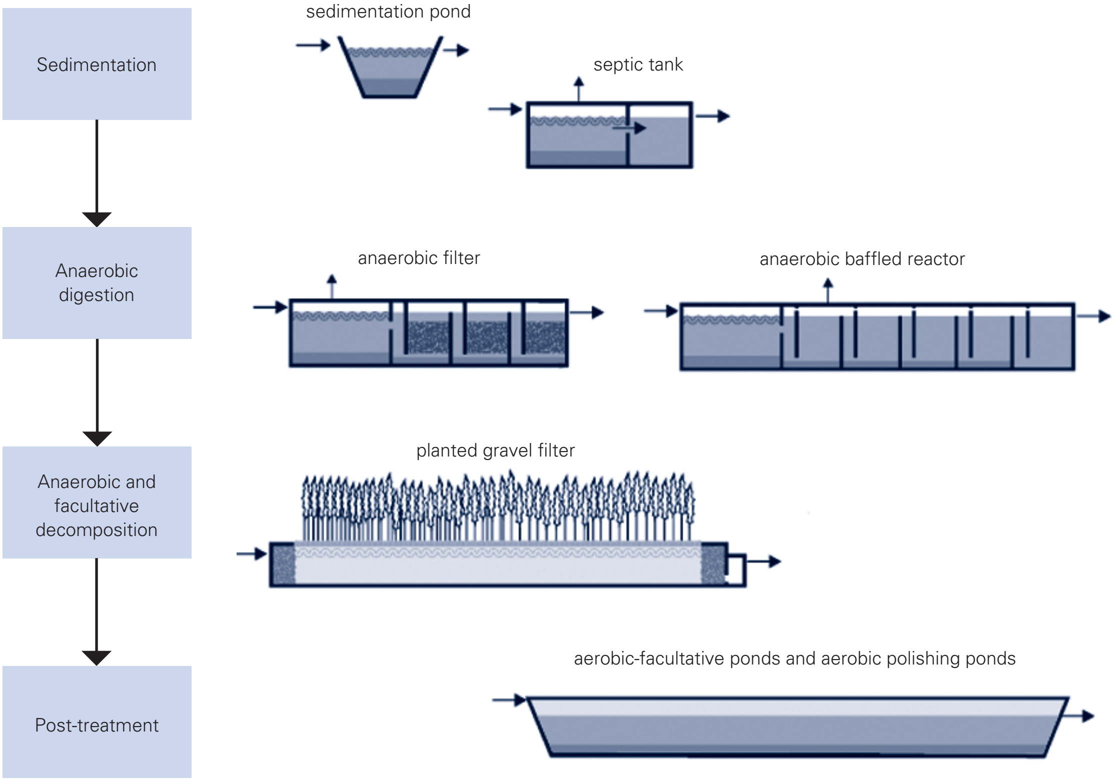
- DEWATS encompass an approach, not just a technical hardware package, i.e. besides technical and engineering aspects, the specific local economic and social situation is taken into consideration
- DEWATS provide treatment for wastewater flows with close COD/BOD ratios from 1 m^3 to 1000 m^3 per day and unit
- DEWATS can treat wastewaters from domestic or industrial sources. They can provide primary, secondary and tertiary treatment for wastewaters from sanitation facilities, housing colonies, public entities like hospitals, or from businesses, especially those involved in food production and processing.
- DEWATS can be an integral part of comprehensive waste-water strategies. The systems should be perceived as being complementary to other centralised and decentralised wastewater-treatment options
- DEWATS can provide a renewable energy source. Depending on the technical layout, biogas supplies energy for cooking, lighting or power generation
- DEWATS are based on a set of design and layout principles. Reliability, longevity, tolerance towards inflow fluctuation, cost efficiency and, most importantly, low control and maintenance requirements

- DEWATS usually function without technical energy inputs. Independence from outside energy sources and sophisticated technical equipment provides more reliable operation and, thereby, fewer fluctuations in effluent quality. Pumping may be necessary for water lifting
- DEWATS are based on a modular, technical configuration concept. Appropriate combinations of treatment modules can be selected, depending on the required treatment efficiency, costs, land availability, etc.
- DEWATS units are quality products. Though they can be constructed form locally available materials and can be implemnted by the local workforce, high quality standards in planning and construction habe to be met. For sound DEWATS design a good comprehension of the process of wastewater-treatment is essential
- DEWATS require few operation and maintenance skills. While most operational tasks can be carried out by the users, some maintenance services might require a local service provider. In some cases, both operation and maintenance can be delivered by a service provider
- DEWATS can reduce pollution load to fit legal requirements. Like all other wastewater-treatment systems, generated solid waste (sludge) must be handled, treated and disposed of in accordance with hygiene and environmental standards
- DEWATS considers the socio-economic enviroment of a given location. Neglecting these conditions will result in the failure of the technology

3.2 DEWATS – a brief insight into technical configuration

Typical DEWATS combine the following technical treatment steps:

- primary treatment – in sedimentation ponds, settlers or septic tanks
- secondary treatment – in anaerobic filters, anaerobic baffled reactors or anaerobic and facultative pond systems
- secondary aerobic/facultative treatment – in horizontal gravel filters
- post-treatment – in aerobic polishing ponds

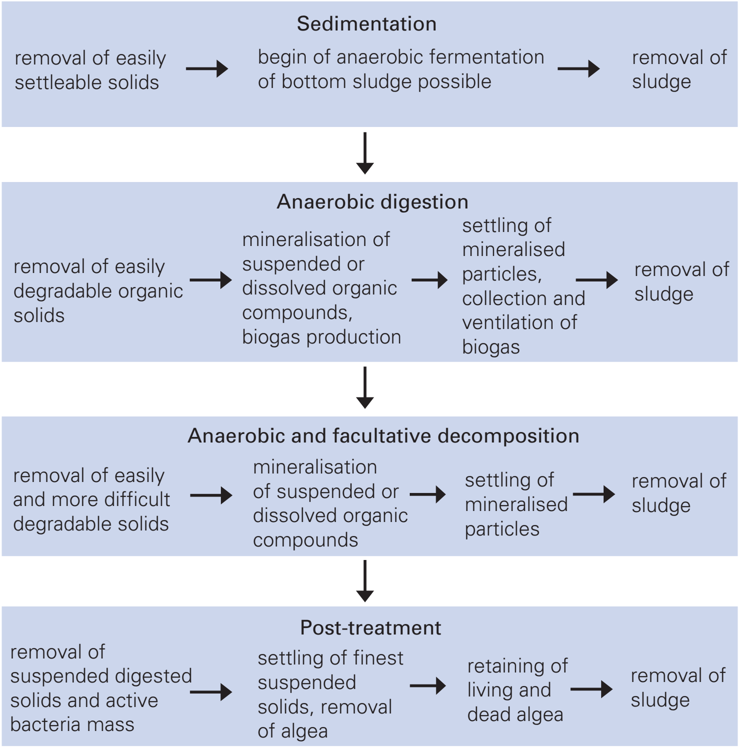


Picture 3_1: DEWATS configuration scheme

The selection of appropriate technical configuration depends on the:

- volume of wastewater
- quality of wastewater
- local temperature
- underground conditions
- land availability
- costs
- legal effluent requirements
- cultural acceptance and social conditions and
- final handling of the effluent (discharge or reuse)

DEWATS rely on the same treatment processes as conventional treatment systems:



Picture 3_2: Typical succession of treatment processes within DEWATS

3.3 DEWATS – good practice examples/applications

In recent years, DEWATS have been implemented at many different locations by various institutions. Gathered experience shows that each location demands its own approach. Below, a number of "good practice examples/applications" of DEWATS are presented. These are is not meant to be exhaustive; they highlight different aspects of DEWATS implementation.

3.3.1 DEWATS/CBS – Community Based-Sanitation Programme in Alam Jaya, Tangerang, Java, Indonesia

Alam Jaya is a slum in the middle of an industrial area in Jakarta. Most residents work in the nearby factories. Due to a high migration rate, social structures are weak. The level of infrastructure development is low. Housing is poor with insufficient water supply.

Sanitation facilities in the settlement are totally insufficient in terms of quality and quantity. Wastewater is discharged into the environment without any treatment, posing a permanent threat to human health.

Picture 3_3: Housing in Alam Jaya

3 DEWATS – Sustainable treatment of wastewater at the local level

Bina Ekonomi Sosial Terpaudu (BEST), (Institute for Integrated Economic and Social Development) a Tangerang-based non-profit organisation, has been promoting "Community-Based Sanitation Centres" since 1999. The centres provide basic sanitation facilities, such as toilets, bathrooms, a laundry area and "water points". The total wastewater flow is treated in a DEWATS. In the meantime, 33 Community-Based Sanitation Centres have been implemented in the Tangerang and Surabaya areas, serving 14,800 users and treating 1,197 m^3 of wastewater per day.

Picture 3_4: Typical sanitation facilities in Alam Jaya

Picture 3_5: New Community-Based Sanitation Centre in Alam Jaya

An intensive discussions process within the community preceded the decision to build a Community Sanitation Centre:

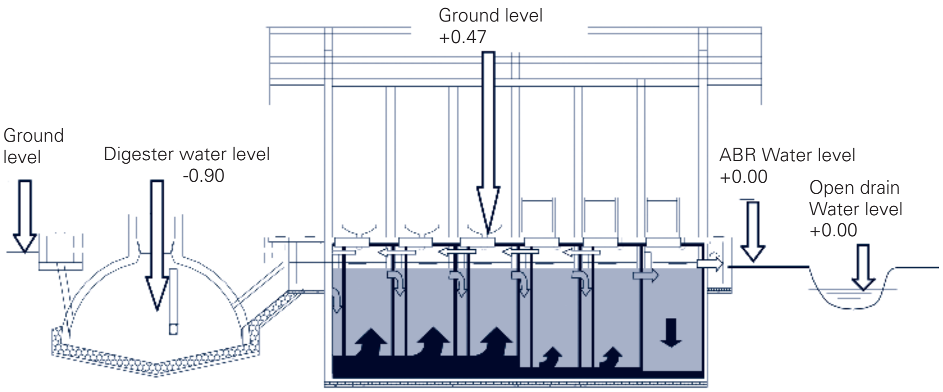
- The residents' desire for on-site toilets could not be met, due to the small size of the houses and plots
- The residents already use public toilets
- There was great interest in a reliable "water supply point"
- Residents expressed their willingness to pay for water-supply and sanitation services

Picture 3_6: Toilet at a Community-Based Sanitation Centre in Alam Jaya

The wastewater of the residents of the Alam Jaya quarter RT 02 RW 06 (65 households with 325 people) has the following parameters:

Source of water	domestic
Volume	37.5 m^3/day
Daily peak-flow hours:	16 h
COD, influent:	743 mg/l
BOD, influent	391 mg/l
HRT in baffled tank	30 h
Minimal digester temperature	30°C
Organic load (BOD_5):	0.34 kg/m^3/d
Number of up-flow chambers	6 chambers
Volume of baffled reactor	49.39 m^3
COD, effluent	137 mg/l
BOD_5, effluent	62 mg/l

Table 2:
Data of Alam Jaya plant



Picture 3_7:
Section of Community-Based Sanitation Centre in Alam Jaya

3.3.2 DEWATS/CBS – Community-Based Sanitation Programme in Ullalu Upanagara, Bangalore, India

Ullalu Upanagara is a peri-urban slum, located south-west of Bangalore, with 3,569 households and 17,325 people of different ethnic groups. The socio-economic situation of the residents is critical: in adequate basic amenities, high unemployment, low iteracy. Women in particular face social hardship with in their families and the community.

The weak socio-economic conditions are reflected in the infrastructure development. Access to reliable drinking-water supply, to proper housing and to clean sanitation is virtually non-existent. Only 21% of the households have their own toilet. The residents defecate openly hindered by recently set up fencing.

Grama Swaraj Samithi (GSS), a local NGO, has been working in Ullalu Upanagara in the field of preventive health care since the 1990s. Since 2001, GSS has been promoting Community-Based Sanitation within the community. In close collaboration with the residents and local authorities, the construction of two sanitation centres was decided on. The implementation process was carried out as a pilot-programme, to test the application of participatory, administrative and technical instruments of the Community-Based Sanitation programme for the area.

Picture 3_8: Infrastructure is poor in Ullalu Upanagara

The participatory planning process resulted in the following layout of the overall complex:

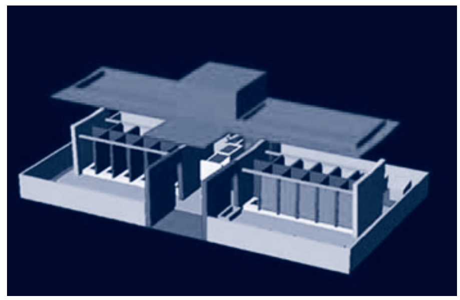
- 2 separate sections – one for women, one for men
- 11 toilets and 1 bathing unit per section
- 12 laundry facilities – 8 for women, 4 for men
- Fresh-water consumption:
  – 11.5 m^3 per day
  – water connection and supply assured by Zilla Panchayat
  - use of rainwater harvesting tank during the rainy season
- Source and quantity of effluent:
  – toilet and bathing wastewater: 7.5 m^3 per day
  – laundry wastewater: 4.0 m^3 per day
- Low maintenance:
  – no taps in toilets and bathing units
  – minimum electrical devices
- Security
  – female and male sections visibly separated
  – entrance area for control and collection of service charges

Picture 3_9: Community-based sanitation center under construction

Construction of the sanitation and DEWATS units incurred the following costs:

- Cost for the sanitation unit: Rs. 4,38,986.00 (US$ 9,475)
- Cost for the DEWATS unit: Rs. 2,91,552.00 (US$ 6,293)
- Total cost per complex: Rs. 7,61,188.00 (US$ 15,767)
- Cost per toilet seat: Rs. 34,600.00 (US$ 747)

Picture 3_10: Newly inaugurated sanitation centre



Picture 3_11: Computer drawing of a sanitation unit

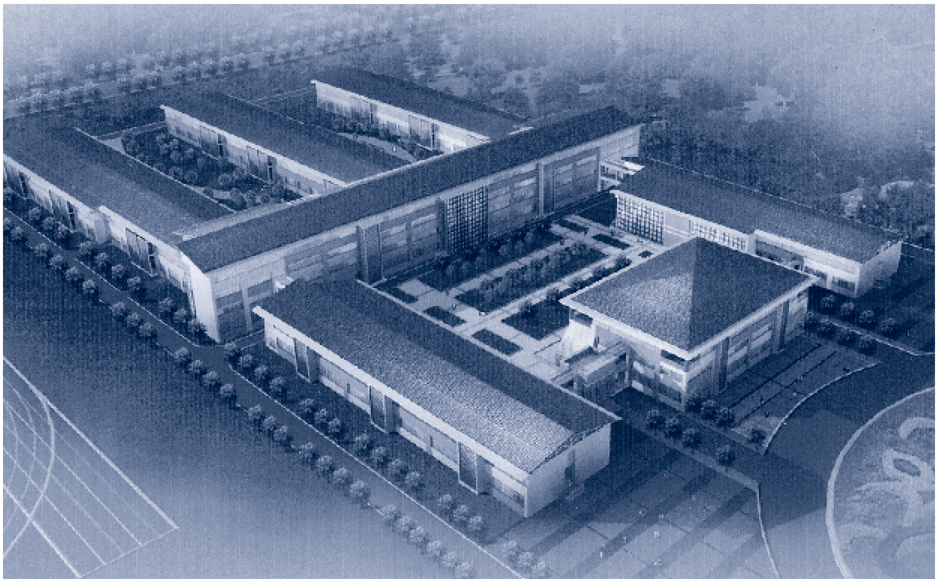
Picture 3_12: The Community-Based Sanitation programme was closely planned in collaboration with the future "users"

3.3.3 DEWATS at public institutions – Sino-German College of Technology, Shanghai, China

The Fenxian campus of the Sino-German College of Technology at East China University of Science and Technology is located an hours drive from Shanghai. An of engineering college, its campus was planned for 6.500 teachers and students.

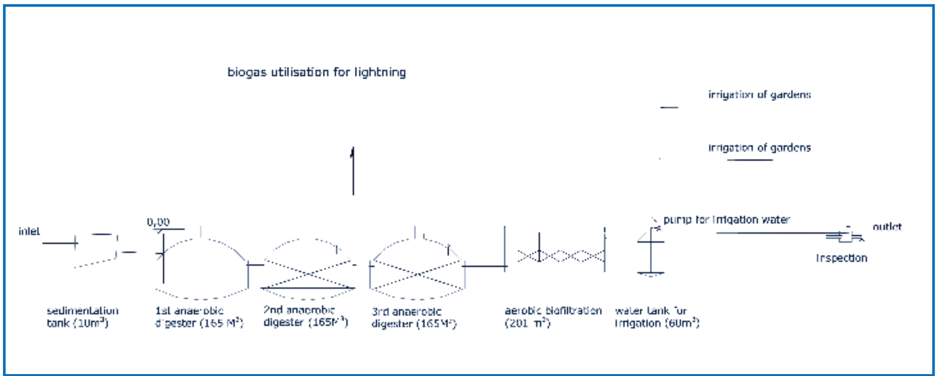
The challenge for the school's authorities was to find a reliable and efficient solution for treating their wastewater in accordance with the Environmental Standard GB/T 18921-2002 (2nd stage). Tight budget constraints for initial investment and operation restricted the possible wastewater-treatment options.

The campus wastewater consists of toilet effluent from the teaching building, as well as polluted water from machinery-maintenance processes. The DEWATS technical configuration had to consider therefore. Oil, NH_3-N, grease and iron chippings, besides the normal parameters of COD and BOD_5.

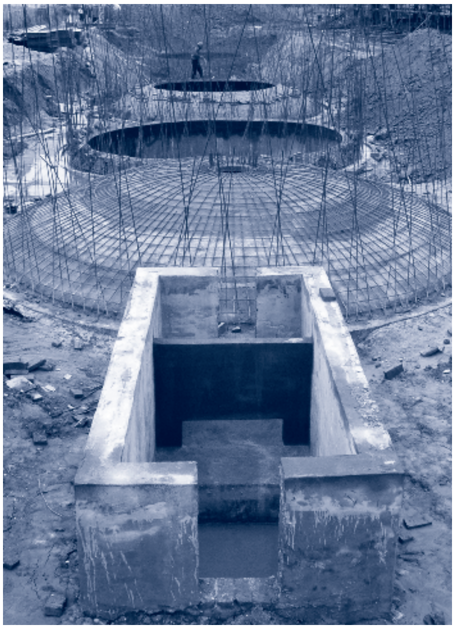


Picture 3_13: View of the college campus

The chosen DEWATS consists of a module for grease separation and sedimentation, an anaerobic digester & filter, a horizontal sand filter and an irrigation tank. Operation started in September 2004. The effluent is used to irrigate compound gardens, while biogas is used to light campus street lamps. The project costs were calculated at 960,000 RMB (US$ 115,942).



Picture 3_14: Schematic drawing of the biogas unit



Picture 3_15: View of campus buildings and biogas street lights

Picture 3_16: DEWATS under construction

The effluent of the plant shows that the required discharge standards can be met:

	Primal water	Sand sedimentation pond	Anerobic pond UBF	Sand filter	Aerobic pipe	Testing well	Required legal standard
Daily waste-water flow (m^3)	146.25	146.25	146.25	146.25	146.25	146.25	
Capacity m^3		10	495	195	5	1	
HRT (h)			81	32	0.8		
COD_{cr} mg/l removal rate	800	720 10%	108 85%	91.8 15%	87.21 5%	87	100
BOD_5 mg/l removal rate	400	360 10%	39.6 89%	31.68 20%	28.5 10%	28.5	30
SS mg/l removal rate NH_3-N mg/l removal rate	 200 80	180 10%	90 50% 40 50%	45 50% 16 60%	 14.4 10%	45 14.4	150 15
Oil mg/l removal rate	20	10 50%				10	15

Table 3: Water-treatment data

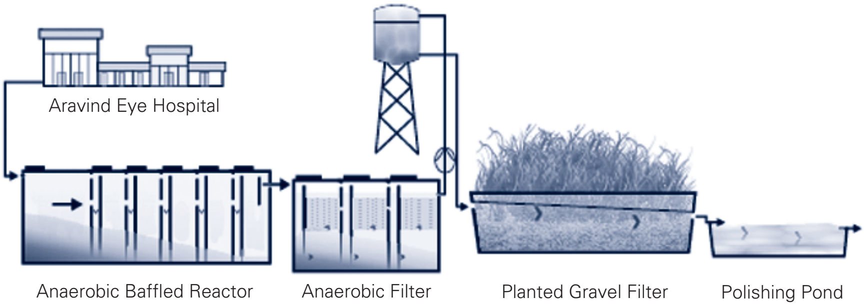
3.3.4 DEWATS at public institutions – Aravind Eye Hospital in Thavalakuppam, Pondicherry, India

The Aravind Eye Hospital in Thavalakuppam belongs to the Tamil Nadu-based Aravind Eye Care System. The philosophy of the Aravind System is to provide services to the rich and poor alike, while achieving financial self-sustainability. This is achieved through high-quality, large-volume care and efficient management.

The hospital in Thavalakuppam has the capacity to treat 750 in patients (600 free admissions and 150 paid) and an additional 900 out patients. 300 paramedical staff are housed in 26 residential quarters.

Due the water scarcity in the region, the hospital management expressed strong interest in a wastewater-treatment solution, that permits the reuse of treated water.

The chosen DEWATS was designed to treat approximately 307 m³ of domestic wastewater from toilets, bathrooms and kitchens per day. Efficient land use had the highest priority in treatment-process selection.



Picture 3_17: Schematic drawing of the DEWATS at Aravind Eye Hospital

The effluent of the DEWATS irrigates a garden with 300 trees planted in avenues, 250 coconut trees, 50 mango trees and 45,000 sq ft of lawns, covered with Korean grass and flowering plants. In 2004, the hospital was honoured with the Pondicherry Government's award for the best garden.

Picture 3_18: Polishing pond of Aravind Eye Hospital's DEWATS

Picture 3_19:
Horizontal filter with *canas indica, reed juncus* and papyrus plants

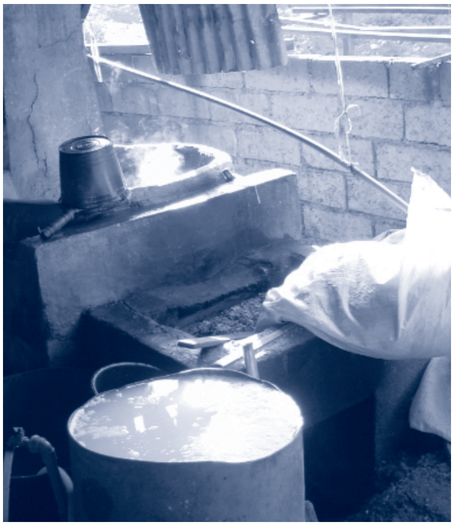
Picture 3_20:
Baffled reactors are used as a parking lot

3.3.5 DEWATS/SME-Cluster approach – Kelempok Mekarsari Jaya small-scale industry cluster, Denpasar, Bali, Indonesia

Mekarsari Jaya is a small-scale industry cluster in Pucuksari Selatan, Banjar Batur, Denpasar. It consists of 54 entrepreneurs, engaged in tofu production and chicken slaughtering. At the same time, Mekarsi Jaya is a settlement area for migrants from other parts of Indonesia. Due to the poor infrastructural conditions, the area is considered a "slum" by the local residents.

Wastewater from domestic and industrial sources is generally discharged to nearby "dead water" channels without any treatment. But recently enforced environmental regulations, mean that enterprises are forced to treat their wastewaters before discharge.

The project was planned and implemented by Bali Focus, a Denpasar-based NGO. Due to the settlement structure and topographical condition of the area, the implementation of a central treatment unit for Mekarsari Jaya faced major technical obstacles. In order to meet the legal requirements of the authorities, it was decided to implement two DEWATS in the area. While one system in Northern Pukusari serves 11 tofu-processing units and 5 chicken-slaughter houses, a second system in Southern Pucuksari Selatun serves 7 processing plants.



Picture 3_21: Tofu processing causes high water pollution in Mekarsari Jaya

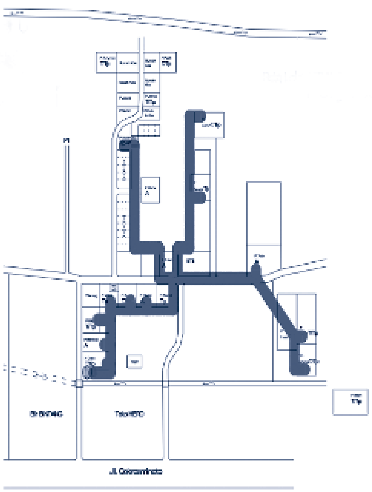
Picture 3_22: Domestic and industrial wastewater is discharged to channels without treatment

Wastewater analysis shows high loading of the wastewater:

- Northern unit – 50 m³/day wastewater influent with a BOD of 7000 mg/l and COD of 11000 mg/l.

- Southern unit – 20 m³/day wastewater influent with a BOD of 5000 mg/l and COD of 8000 mg/l.

Topography and settlement structure (densely populated) were the decisive factors for technical plant layout. A bio-digester, followed by an anaerobic filter, were found most suitable to treat the highly loaded wastewater.

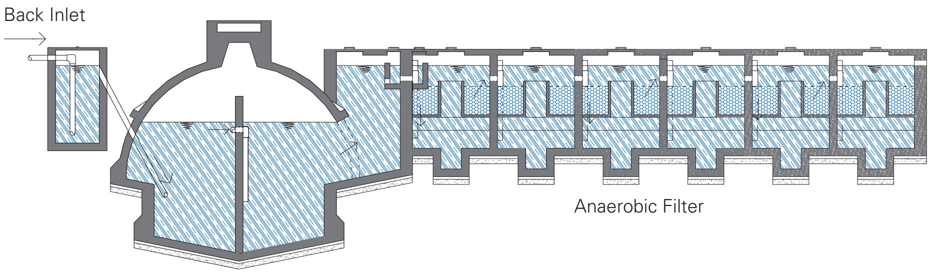


Picture 3_23: DEWATS treats wastewater from several industrial units (Sewerage system= blue lines)

The following data characterises treatment in the baffled reactor of the northern unit:

Source of water	domestic
Volume	50 m³/day
Daily peak-flow hours:	12 h
COD, influent:	1.500 mg/l
BOD_5, influent	1.300 mg/l
HRT in baffled tank	17.5 h
Minimum digester temperature	30°C
Number of up-flow chambers	3 chambers
Volume of baffled reactor	36.45 m³
COD, effluent	335 mg/l
BOD_5, effluent	191 mg/l

Table 2a



Picture 3_24: Technical layout of a DEWATS unit in Mekarsari Jaya

3.3.6 DEWATS/SME – Alternative Food Process Private Ltd. Bangalore, Karnataka, India

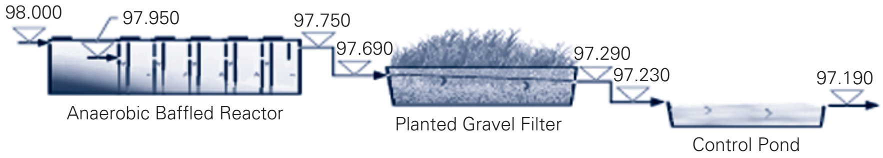
The food-processing unit is located in the suburbs of Bangalore city. The company operates a gherkin-processing plant, where selected gherkins are washed, prepared, pickled and stored over a period of 12 days before export.

The company caters semi-finished products to leading brands. High quality production and adherence to delivery standards of international markets are the top priority. The company employs around 100 people and handles 8 to 10 tonnes of gherkins per day.

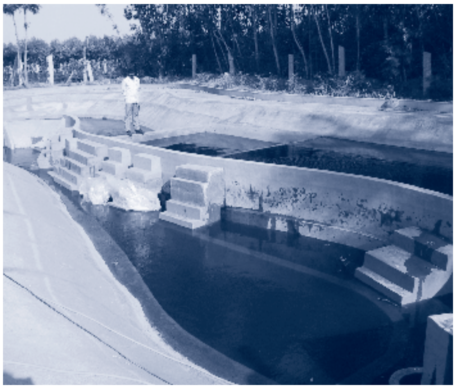
Picture 3_25 and 3_26: The products of alternative food process private ltd. meet high delivery standards for national and international markets

The treatment of 29.1 m³ highly loaded wastewater is required daily. Due to water shortages in the area, water reuse is desirable.

To find the best treatment solution, a comprehensive analysis of the different wastewater streams was undertaken. By handling certain wastewater streams separately from each other, adequate treatment solutions could be applied to each situation:

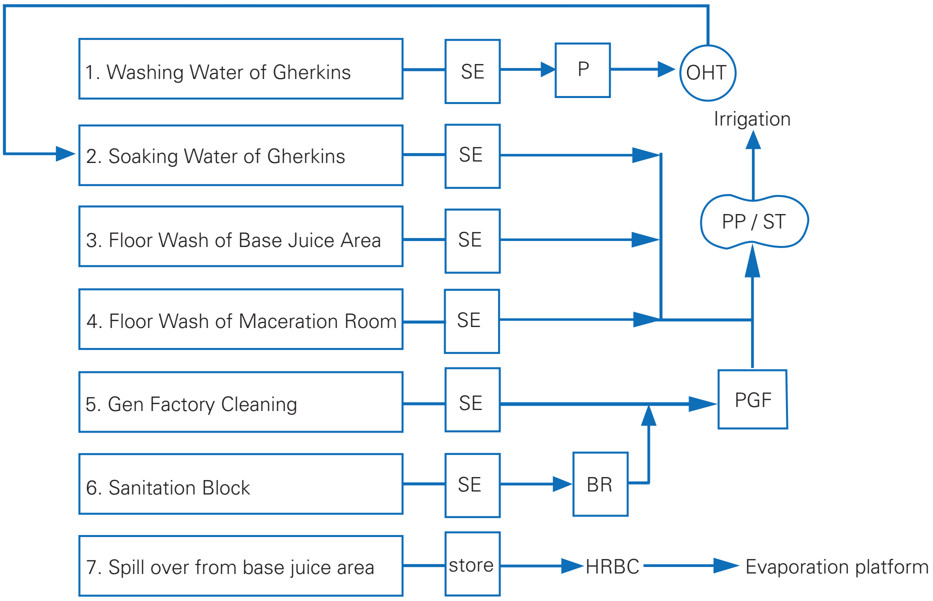


Picture 3_27: Schematic drawing



Picture 3_28:
The anaerobic filter under construction

Picture 3_29:
About 29.1 m³ highly loaded waste water has to be treated



Picture 3_30:
System layout (SE: Settler, BR: Baffle Reactor, PGF: Planted Gravel Filter, ST: Storage Tank, PP: Polishing Pond, HRBC: High-rate Brine Condenser (evaporation), OHT: Overhead tank, P: Pump)

3.3.7 Infrastructural development in rural China – Longtan Village, Danleng County, Szechuan Province, China

The Chinese government aims to improve rural livelihood by promoting the enhancement of rural infrastructure through different public programmes. Road construction, housing, electricity provision, biogas utilisation, water supply and wastewater schemes – as well as solid-waste management – are part of multiple village modernisation programmes.

Longtan Village has a population of 965 people living in 262 households. Agricultural production on approximately 56.7 ha of land is the main income source for the residents. Traditionally, paddy and oil seeds were cultivated. However, economic reforms have Longtan brought significant changes to the village has begun market production of oranges, grapes and oil seeds, while raising 1250 pigs in 2005. A household's average annual income is about 3,113 RMB per person (US$ 420).

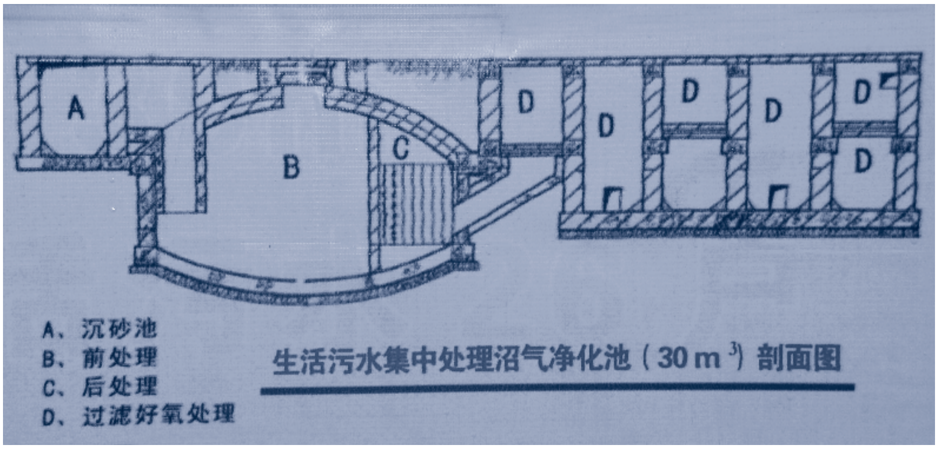
Public authorities in rural China have the challenge meeting of legal wastewater discharge standards. New air-quality standards have also been issued, demanding a different treatment of rice-harvest residues, which were traditionally burned. As a result, decentralised wastewater-treatment systems are promoted. A combination of anaerobic and of aerobic-treatment units is applied to treat animal dung, human faeces and residues from agricultural production. Biogas provides a renewable-energy source, while slurry can be used in organic farming.

Picture 3_31: DEWATS treats human faeces and agricultural residues

Picture 3_32: DEWATS-generated biogas is used for multiple purposes, such as water heating

The village's development plan stipulates that 120 households should be connected to biogas units, each with a volume of 10 m^3. Rice residues are processed in a chaff cutter before being emptied into the digesters. Bio-digesters with a volume of 3.5 m^3 are mandatory for households without paddy production. Where possible, homes are connected to one of two DEWATS plants in the village. The treated wastewater is discharged into the open drainage system, which crosses the village.

Picture 3_33: Infrastructural development programmes aim to modernise Chinese villages

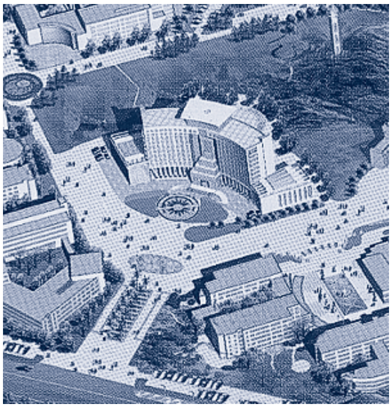


Picture 3_34 DEWATS – settler, bio-digester, anaerobic baffled reactor and horizontal filters (not shown)

3.3.8 DEWATS in integrated municipal planning – Wenzhou University, Zheijang Province, China

Since the 1980s, the government of Zhejiang Province has been promoting DEWATS, particularly in urban areas, which are not connected to centralised systems. Today, many of the province's sources of domestic wastewater, such as public toilets, apartment buildings, schools, hospitals and universities are served by these treatment systems. Apart from domestic applications, decentralised wastewater-treatment solutions are applied at small- and medium-scale enterprises, like slaughterhouses, food processing and animal-husbandry units.

The Wenzhou New Energy & Environmental Design Institute (WNEEDI), an Institute of the Rural Energy Office Wenzhou, is active in the dissemination of innovative renewable-energy and ecological wastewater-treatment projects (biogas plants, DEWATS, solar thermic systems, hydro rams) within the city and Wenzhou County. WNEEDI started by promoting of biogas plants 50 years ago and has slowly shifted its main activities to wastewater treatment in urban areas.



Picture 3_35:
The central administration building of the University of Wenzhou

Picture 3_36:
Arial view of the University of Wenzhou campus

Within this context, WNEEDI was responsible for the planning and implementation of an integrated wastewater concept for Whenzhou University, the first university run jointly by the government and business. In 2005, the university had approximately 10,000 students.

The DEWATS implemented at the University campus are viewed as the ideal long-term solution. The treatment facilities will grow incrementally, in line with the addition of new buildings and the overall growth of the campus.

Today, the university uses multiple DEWATS, with a total reactor volume of about 90,000 m^3. Nearly all buildings, including the dormitories, have their own primary treatment unit, which connects to shared, secondary treatment units. Units of approximately 20 different treatment volumes, ranging from 40 to 800 m^3, have been implemented.

All systems consist of pre-treatment in fixed dome modules. Two to four digesters are usually connected in series. After anaerobic treatment, the wastewater is aerobically treated by flowing over cascades. Final treatment is provided by two to four horizontal-flow sand filters in series.

Implementation is carried out by contractors, specialised in decentralised wastewater treatment. To ensure gas-tight construction of biogas domes, certification is required. The local Rural Energy Offices are responsible for certification; Wenzhou County has eight certified building contractors.

Picture 3_37: The project team tests the treatment performance.

Picture 3_38: Construction of the anaerobic filter (in front)

4 Mainstreaming DEWATS – strategic planning and implementation of sustainable infrastructure

4.1 Strategic planning of sanitation programmes

Nowadays public authorities are challenged to provide sanitation and wastewater-treatment services on a large scale. Mainstreaming decentralised wastewater-treatment solutions is one of the key elements for sustainable infrastructure development.

Comprehensive wastewater strategies may consider different options for the treatment and discharge of wastewater:

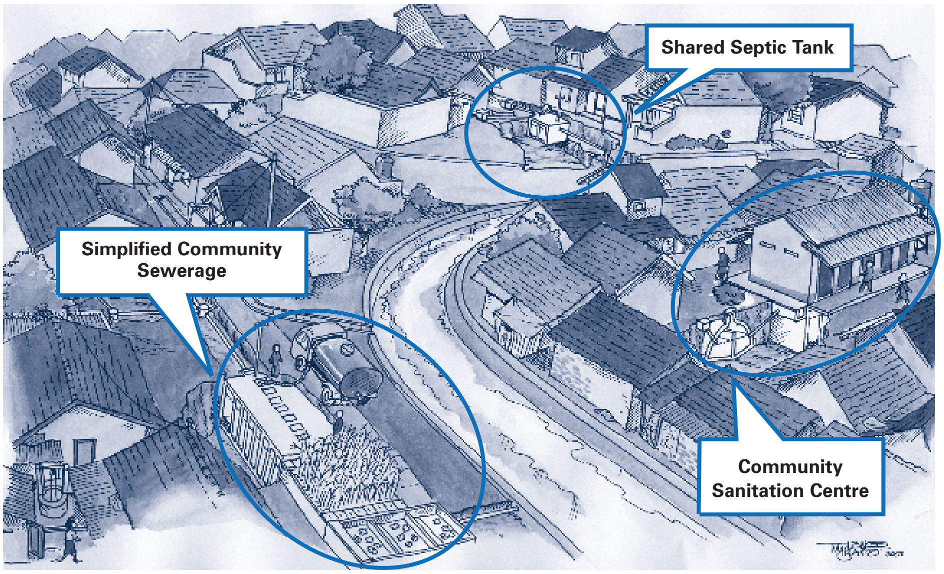
- Treatment in a centralised plant, which is connected to a combined or separate sewer system
- Treatment in several medium-sized treatment plants, which are connected to a combined or separate sewer system
- Primary and secondary treatment in decentralised plants, which are connected to a sewer line, leading to a common plant for final treatment
- Completely decentralised treatment with final discharge, reuse, or connection to communal sewerage
- Controlled discharge without treatment (ground percolation, surface-water dilution)

The final decision, on which treatment option is most suitable for a given water pollution problem, should be based on a number of different considerations, which are discussed in greater depth later in this book. Different options may be considered for residential areas:

- Simplified community-sewerage systems with household-based sanitation systems are preferred in areas where the residents have sufficient financial resources and households have sufficient space. On average, 20 to 100 families are connected to one system. The system consists of toilets and bathrooms within each household. The wastewater is directed to a DEWATS by shallow, narrow sewer lines.
- Shared septic tanks present a simpler version of the household-based sanitation system with off-site treatment. A smaller cluster of about 10 to 50 households is connected to a community septic tank. The system contains toilets and bathrooms within each household. Wastewater is channeld to the septic tank by shallow small-diameter sewer lines. The wastewater cannot be discharged directly to the aquatic environment, due to the low effluent quality of the septic tank. The system is, usually only applied, therefore where soil conditions allow the direct infiltration of the effluent without any harm to the groundwater.

- Community Sanitation Centres (CSCs) are appropriate in areas where financial resources are very limited and most residents live in rented rooms or huts, leaving no space for in-house sanitation. The centre is established at a central location within the settlement and offers different services as requested by the community. Services can include water points, toilets, bathrooms and laundry areas. Each CSC is connected to a DEWATS, usually located underground below the Centre. CSCs are usually guarded and operated by paid staff.

The experience gathered in multiple efforts to create efficient and cost-effective sanitation and wastewater-treatment strategies clearly shows that, without comprehensive legal frameworks and efficient law enforcement, without institutional capacities within public and private services, without relevant financial resources, and without awareness at the household or enterprise level, the hoped for health and environmental standards cannot be achieved.



Picture 4_1:
Different treatment options within a CBS programme

4 Mainstreaming DEWATS – strategic planning and implementation of sustainable infrastructure

In many countries, new legal regulations have favoured a rapidly increase in the demand for decentralised wastewater-treatment systems. For many public and private entities DEWATS poses the only solution for complying with legal requirements within the time constraints. The situation raises the question: How can these technical options be integrated effectively into regional and municipal planning processes, in order to reach an economy of scale?

Since the goal of public authorities is not to promote specific technical solutions, but rather to achieve political and administrative targets, the following questions must be considered by all key decision-makers:

- Under which conditions should DEWATS be preferred over other technical solutions?
- What are the advantages of DEWATS over other wastewater-treatment options?
- How can a legal and institutional framework be created, which facilitates comprehensive sanitation and efficient wastewater-treatment schemes?
- What are the core elements of such schemes?
- Who are the stakeholders, who should be involved in the process?
- What kind of approach is required to ensure efficient, cost-effective and sustainable implementation?
- How can the implementation of such schemes be initiated and maintained?

The government of Indonesia, for example, evaluated multiple efforts in the sanitation sector, as a basis for creating an implementation scheme for a nation-wide programme. It was concluded that the exclusive top-down approach must be replaced by a conceptual framework, which includes "demand-driven services", "multi-stakeholder involvement", and "multi-task planning" as guiding principles.

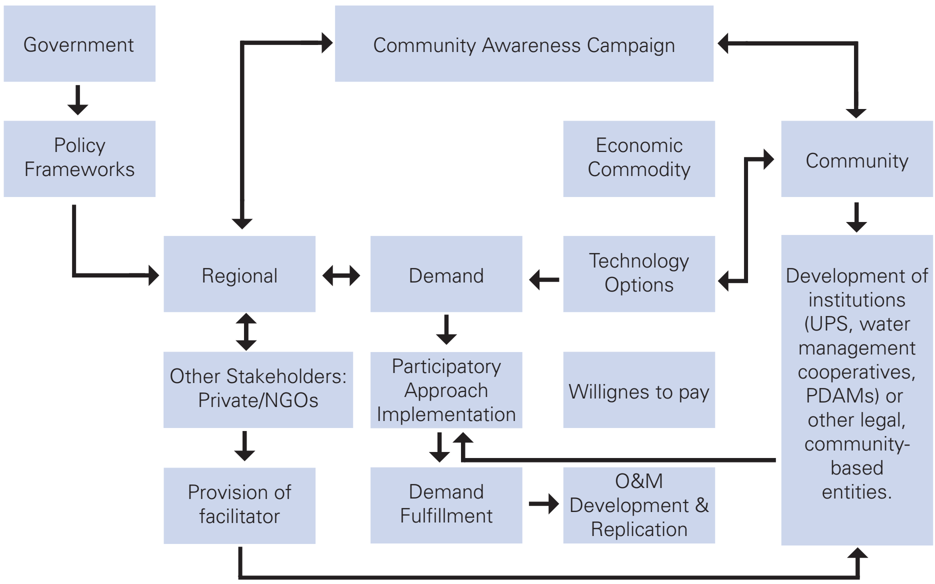
In order to overcome the poor long-term performance of many projects and initiatives, the government of Indonesia has decided that further guiding principles should play an integral part in any planning and implementation activities:

- Sustainability of financing
- Sustainability of technical know-how
- Sustainability of environmental management
- Sustainability of infrastructural management
- Sustainability of social interaction

This conceptual framework reflects the international discussion about how sanitation and wastewater treatment services can have the optimal sustainable impact.

The following features present the underlying principles of an efficient and cost-effektive programme:

- Comprehensive legal regulations
- Efficient law enforcement
- Target-orientated local and municipal planning
- Demand-responsive approach
- Comprehensive assessment of local and community needs
- Service orientation
- Multi-stakeholder involvement
- Appropriate choice of technology
- Multi-task planning
- Financial analysis and long-term financial planning
- Sound planning and monitoring of the implementation process
- Capacity building
- Step-by-step implementation



Picture 4_2: Conceptual framework of Indonesia's National Sanitation Programme

4.2 Legal framework and efficient law enforcement

A comprehensive legal framework and its efficient enforcement at the local level are essential to the success of sanitation and wastewater-treatment strategies.

Wastewater-treatment schemes must meet the legal discharge standards, defined within the legislation of each country. Those standards, however, are rarely met in developing countries. The reasons for this are manifold.

In most countries, legal environmental and discharge standards are based on the most scientifically advanced treatment technologies available on the market. Discharge standards in developing countries often refer to those from industrialised countries, where sophisticated treatment technologies can be applied to treat the highly diluted municipal sewage. The different prerequisites in developing countries, including wastewater composition, economic and socio-economic conditions as well as financial and organisational restrictions, create large discrepancies between desired effluent standards and the actual services that can be provided. In some cases, standards thereby achieve adverse effects, as they are considered unrealistic and ignored.

Table 4: Some selected domestic wastewater-data. Source: BORDA

examples	COD g/cap.*d	BOD_5 g/cap.*d	COD/ BOD_5	SS g/cap.*d	Flow l/cap.*d
India urban	76	40	1.90	230	180
USA urban	180	80	2.25	90	265
China pub. toilet	760	330	2.30	60	230
Germany urban	100	60	1.67	75	200
France rural	78	33	2.36	28	150
France urban	90	55	1.64	60	250

At single pollution spots, like hospitals and small-scale industries, compliance with given discharge standards often proves too expensive. Thus, individual polluters frequently decide to either completely ignore the problem or to set up a fake treatment system to please the environmental authorities. In other cases, complicated technology is implemented, but often soon results in the described performance problems.

Indian National Discharge Standards					
			discharge into		
parameter	unit	inland surface water	public sewers	land for irrigation	marine coastal area
SS	mg/l	100	600	200	100
ph		5.5 to 9	5.5 to 9	5.5 to 9	5.5 to 9
temperature	°C	<+5 °C			<+5 °C
BOD_5	mg/l	30	350	100	100
COD	mg/l	250			250
oil and grease	mg/l	10	20	10	20
total res. chlorine	mg/l	1			21
NH_3-N	mg/l	50	50		50
N_{kjl}-as NH_3	mg/l	100			100
free ammonia as NH_2	mg/l	5			5
nitrate N	mg/l	10			20
diss. phosphates as P	mg/l	5			
sulphides as S	mg/l	2			5

Table 5: Source: Central Pollution Control Board, Delhi

It is becoming increasingly apparent that a more realistic approach must be sought:

> "Undue haste in adopting standards, which are currently too high, can lead to the use of inappropriate technology in pursuit of unattainable or unaffordable objectives and, in doing so, produces an unsustainable system. There is a great danger in setting standards and then ignoring them. It is often better to set appropriate and affordable standards and to have a phased approach to improving the standards as and when affordable. In addition, such an approach permits the country the opportunity to develop its own standards and gives adequate time to implement a suitable regulatory framework and to develop the institutional capacity necessary for enforcement."[18]

18 Johnson et all, Institutional Developments, Standards and River Quality, 1996

Recently, an increasing number of countries have launched initiatives to draft more realistic legal frameworks. Regulations cover a wide range of topics, including the practices of service providers, design standards, tariffs, discharge standards and contracts. These regulations, especially design and discharge standards, are carefully adapted to local conditions and no longer just copied from regulations applied in industrialised nations.

For example, in its Water Act the Government of the Republic of South Africa defines differentiated wastewater-treatment and disposal standards, according to wastewater type, quantity and the location of generation. While high standards are applied to areas of high risk, in terms of ecology and health, lower standards are defined for other locations, such as sparsely populated areas. This pragmatic approach widens the scope of applicable technological solutions, ensuring a more site-specific treatment option-selection and thereby increasing the positive impact on health and environment on a larger scale.[19]

19 Ref. Government Gazette No. 20526 8 October 1999.

Comprehensive law enforcement was and is one of the major challenges to the successful implementation of wastewater strategies. Due to weak institutional capacities, the adherence to regulations was and is seldom properly monitored by public bodies. In many countries, the relevant authorities are rarely prepared to carry out performance-orientated site monitoring. Public agents frequently request the implementation of sophisticated hardware, even in cases where a decrease of wastewater pollution might be more efficient and less expensive achieved by wastewater-prevention measures. There is a great necessity for institutional capacity building. On the other hand, the corruption in many countries must be overcome, if the legal framework is to be enforced effectively.

The enforcement of comprehensive legal standards can be perceived as a major driving force for improving the current sanitation situation with efficient and cost-effective wastewater solutions:

- Existing small and medium-scale industries are urged to comply with discharge standards in short term
- New industrial sites, slaughterhouses and hospitals only receive clearance once reliable wastewater treatment is provided
- New housing colonies and residences are only approved if they ensure efficient treatment of the generated domestic wastewater
- Municipalities and local governments are urged to protect surface and groundwater bodies from the intrusion of domestic and industrial wastewaters

A reliable legal framework must be backed up by an efficient policy framework and law-enforcement procedures. Institutional capacities must be created, and standardised law-enforcement procedures must be developed.

Awareness-building campaigns within the civil society can help to create leverage for law enforcement. In many countries, cases have been filed by individuals, neighbourhood groups and NGOs, forcing polluters to close down operations because they were not willing or not able to meet discharge quality standards.

It seems obvious that recent and future ecological developments will be reflected in the legal frameworks. The extensive use of natural resources requires more stringent regulations. Surely economic instruments on the macro level will influence the sanitation sector in the near future. The more fresh-water resources are perceived as a valuable and scarce public asset, the higher water will be priced. Pricing directly influences water consumption and the search for wastewater solutions, which are based on reuse or "closed loop" concepts.

4.3 Target-oriented local and municipal planning

4.3.1 Features of urban infrastructure development

A closer look at the socio-economic structure of a city can provide a first overview of relevant decision parameters for the final selection of appropriate technology.

The dynamic economic growth of most cities in the developing world caused deep social transformation within these societies. Rural areas and villages were rapidly integrated into spreading urban settlements. Agricultural land was converted into new residential and industrial areas. These trends can be still observed almost everywhere.

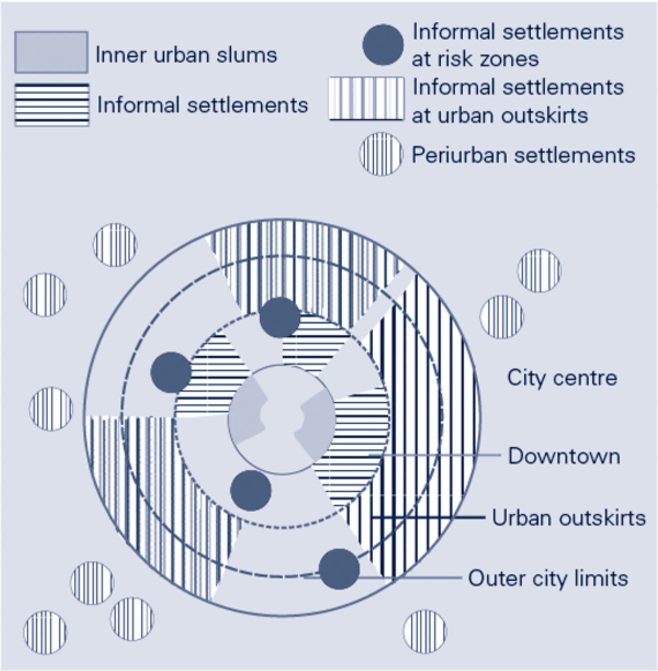
In most cases, this development lacks systematic planning of land use and adequate infrastructural development. By studying urban land-use patterns, one can gain insight into the social stratification and economic diversification of an area. While "wealthy neighbourhoods" are supplied with relevant infrastructure, informal settlements are left with only limited or no access to basic infrastructure. Even if a central sewage system cannot be extended everywhere, "formal" settlements are usually connected to septic tanks, while "informal" settlements have no treatment at all. Wastewater from industrial areas is commonly channelled directly to the closest surface waters.

Since informal settlements are a major driving force in most urbanisation processes, the following land-use pattern is quite common in the larger cities of developing countries.

Close to the city centre, a number of informal settlements exist. These are often found in so called "risk areas", such as dump sites, railway crossings, etc. The livelihood of the dwellers is usually dependent on activities in the informal sector or day labour.

Similar "peri-urban" settlements are found at the outskirts of urban areas. Dwellers of these settlements commonly generate income from day labour and small-scale commercial activities or business. If possible, self-subsistence farming is practised on nearby lands. Due to the unclear situation regarding land ownership – and the general negligence towards the urban poor, there is little public investment in infrastructure in these regions.

Since these areas are most responsible for urban growth, their importance to comprehensive urban-infrastructure development is obvious. Particular entities, such as small-scale industry clusters, schools and hospitals in semi- and peri-urban areas, face the greatest problems in meeting discharge standards.



Picture 4_3:
Informal settlements in greater urban areas of developing countries
Source: GTZ, 2002

4.3.2 Sanitation mapping as a tool for efficient urban-infrastructure development

In recent years Geographic Information Systems (GIS) have become an integral part of comprehensive urban-development strategies. GIS is a tool for visualising parameters, which are relevant for infrastructure development. Sanitation mapping permits the analysis of collected data, like the current situation of sanitation infrastructure, the impact of poor infrastructure on environment, and the driving forces, such as the socio-economic dynamics, of a given location. A database of the following parameters is beneficial for efficient sanitation mapping:

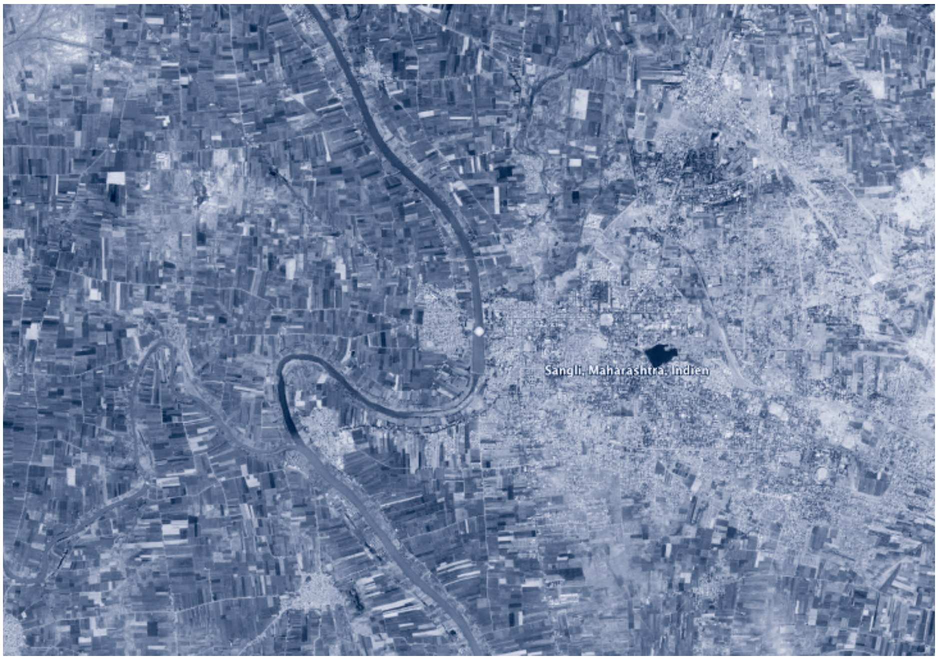
- Topography
- Natural water-drainage systems – rivers, streams, creeks
- Land-use patterns – residential zones, industrial and agricultural areas
- Existing city master-plan
- Existing water-related infrastructure – sewers and water supply
- Main water-pollution sources
- Residential structure
- Population density
- Socio-economic situation of residents
- Existing sanitation facilities
- Community health conditions

GIS can be a powerful tool for poverty-alleviation programmes. Shelter Associates, an NGO based in Pune, India, implements housing programmes in poor areas. Shelter Associates applies GIS to generate a reliable database, which supports systematic programme approaches, as practised at the 'Community Water and Sanitation Facility' at Sangli-Miraj-Kupwad Municipal Corporation (SMKMC).

SMKMC is located on the banks of the Krishna River in southern Maharashtra. In 2001, SMKMC had a population of 478,500. It covers about 118 km². Although the Municipal Corporation is only four years old, almost 15 per cent of its population live in slum settlements. The lack of access to basic infrastructure and civic amenities is a main feature of the area.

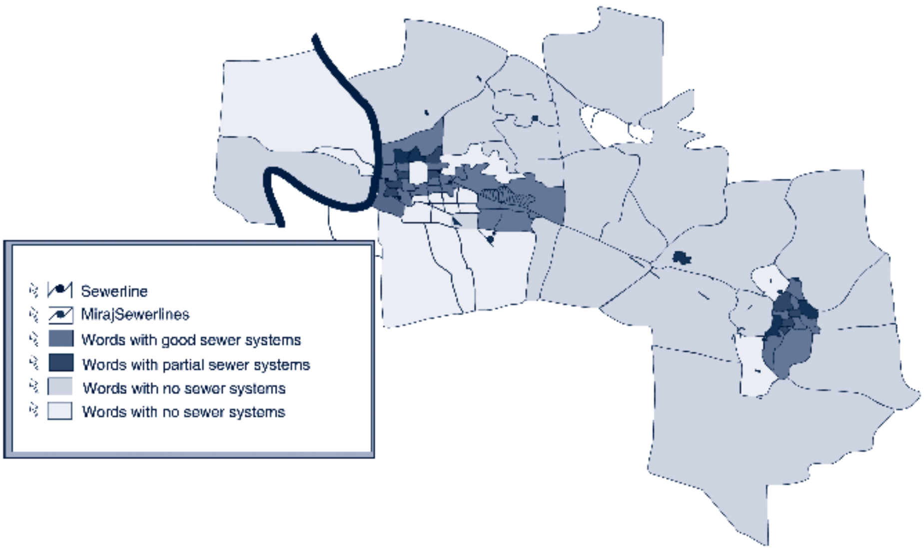
In order to get an overview of the existing sanitation situation, all the SMKMC settlements were mapped by plane table survey methods and each household was surveyed individually. The information was entered in GIS software and a detailed analysis of each slum pocket was compiled. The data generated gave a detailed picture of the existing water and sewage situation. Maps of the dilapidated water-supply network and sanitation facilities were developed.

It became apparent that the city has not undertaken any major improvements or extensions in the past 20 years. As a result, more than 11,500 households in Sangli were left without any basic sanitation access. Information gathered on a household level underlined the linkage between poor sanitation and weak socio-economic structures.



Picture 4_4: Satellite photo of SMKMC (Source: by google earth)

Picture 4_5: Existing sewage system in SMKMC



Picture 4_6: Sanitation-relevant data on household level in SMKMC

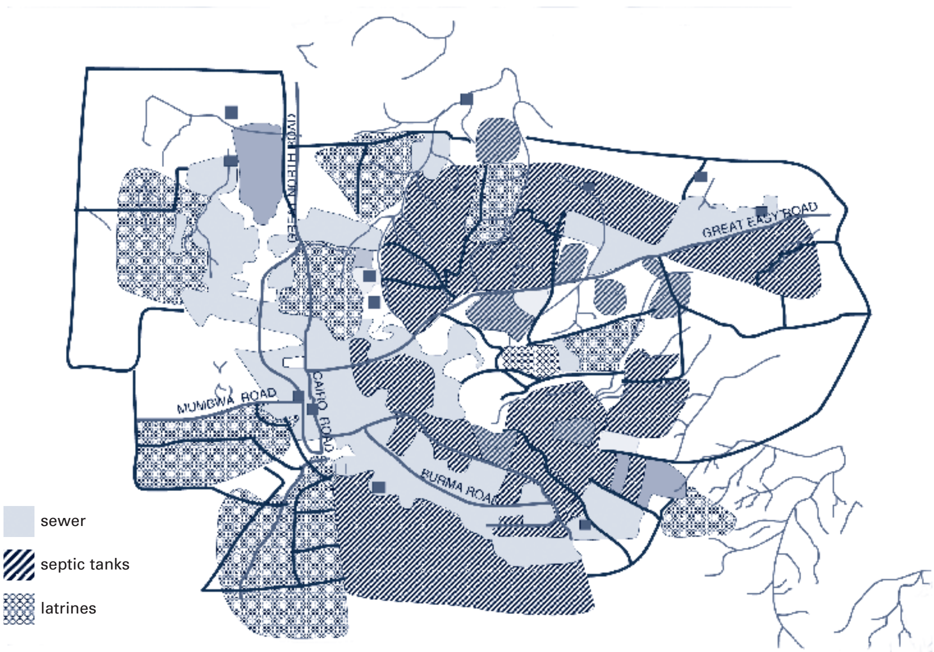
Similar features can be observed in the City of Lusaka, Zambia. A GIS-generated sanitation map shows that there are two main sewage-disposal methods within the urban area:[20]

- centralised waterborne methods, which comprise a sewer network, sewage-pumping stations and sewage-treatment works and
- on-site sanitation methods, like septic tanks and soakaways, pit latrines, aqua privies and cesspools

Additional information, relevant to the future development of a wastewater strategy and the identification of suitable technological options, was compiled:

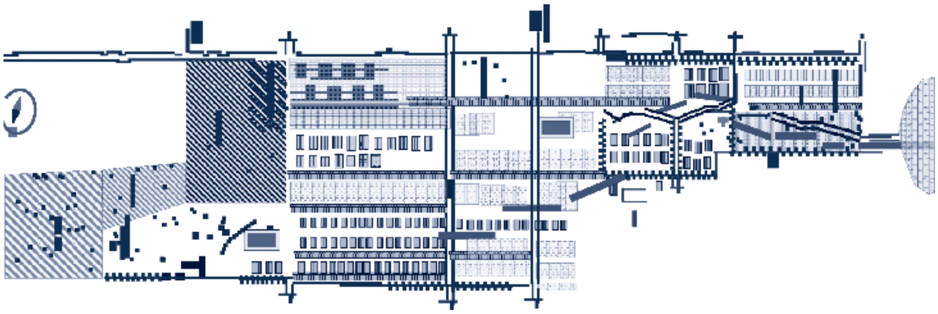
- Only about 30% of the areas, which receive water supply from the Lusaka Water and Sewerage Company, are serviced by a sewer network
- The sewer network is divided into six catchment areas, each serviced by a sewage-treatment plant
- Storm water and sewage waste are drained through separate systems.
- The sewage network operates mainly on gravity flow; few areas are served by pumping stations

20 Urban Development Plans and Infrastructure Services for the City of Lusaka., Lusaka Water and Sewerage Company, 2005



Picture 4_7: Lusaka Sanitation Map

The community-based sanitation programme in Ullalu, Upanagara, Bangalore, India, described in chapter 3 also applied sanitation mapping to find the most effective way to improve the sanitation situation of the large slum's dwellers. Besides the careful assessment of physical parameters, such as topography, land availability and existing infrastructure facilities, comprehensive household surveys were carried out. After detailed analysis, participatory methods for project planning were applied. The combination of physical and social data within the same maps showed the connections between the availability of sanitation facilities at the household level, the socio-economic situation of the dwellers and their preparedness to contribute to the overall improvement of sanitation infrastructure (willingness to pay). The insights-gained were key decision parameters for sanitation-centre site selection. Chosen sites provide both the required physical preconditions as well as a strong acceptance of the new utility by the users.



Picture 4_8: Position of two sanitation complexes within Ullalu slum

For application in full-scale urban planning, sanitation mapping must combine a wide range of relevant parameters. Besides all the data mentioned above, the overall dynamics of current developments and the available resources within the sanitation sector should be included. The tool can then be used to assess whether decentralised wastewater treatment solutions are appropriate for a given location.

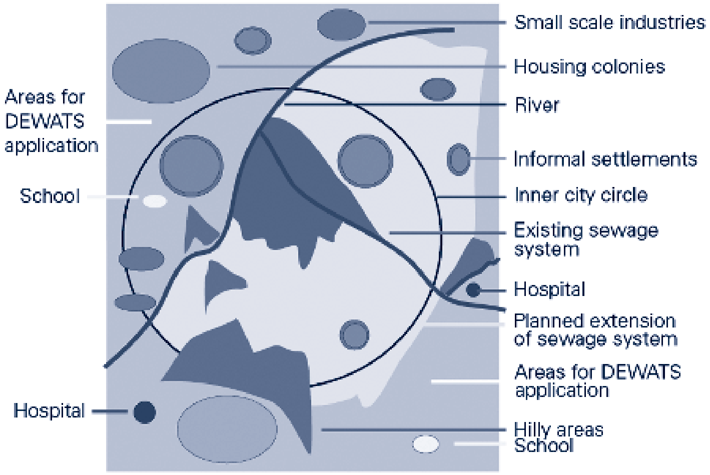
The following locations types are most favourable for the implementation of DEWATS:

- Locations far away from central sewerage and wastewater-treatment systems, or where a connection to such a system is unlikely due to financial reasons
- Locations suffering from water scarcity

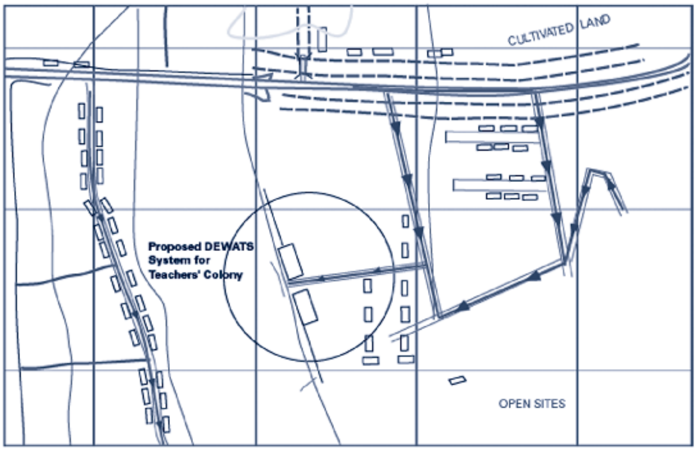
- Locations which are difficult to attach to central sewage systems, due to the topographical profile of the area (hilly areas, ravines, etc.)
- Locations with polluters, such as schools, hospitals, slums, new housing colonies, and small and medium industries, needing immediate and intermediate wastewater-treatment solutions[21]

21 Further planning details will be discussed in chapters 5 & 6

A sanitation map – containing all relevant data and parameters – should help identify those areas of a city, that are most for to centralised and/or decentralised wastewater-treatment approaches.



Picture 4_9: Example of how a sanitation map, detecting areas suitable to centralised and decentralised wastewater-treatment solutions might look



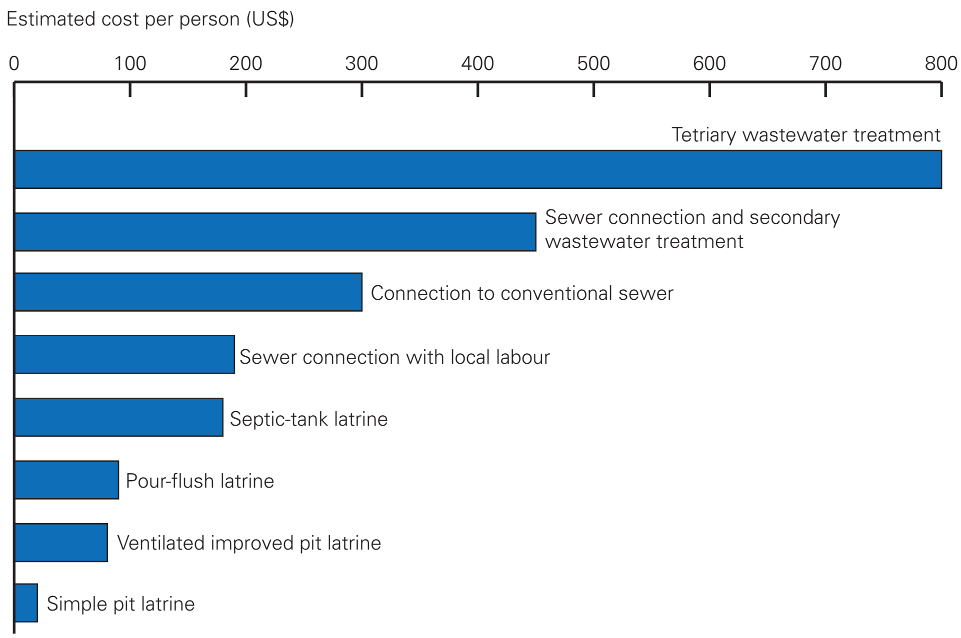
Picture 4_10: GIS-optimised positioning of decentralised sewage and wastewater-treatment facilities within a housing scheme in Karnataka, India

4.4 Financial analysis

4.4.1 Comparative cost analysis for infrastructure development

Economic parameters have a major influence on technology selection. Available funds must be allocated in such a way that the required treatment efficiency is met, while being cost-efficient enough to provide treatment of the desired quantity of wastewater.

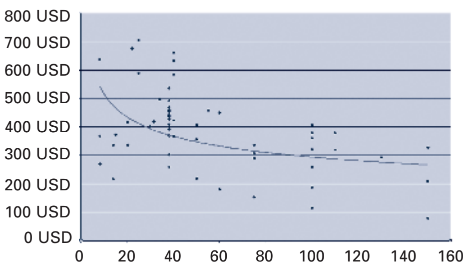
Centralised sewage-treatment systems usually require high investments – not only for the treatment unit itself, but particularly for the sewerage system. Decentralised solutions, therefore, often have a comparative advantage over conventional systems, especially when they are located in dispersed settlements or serve scattered pollution points.

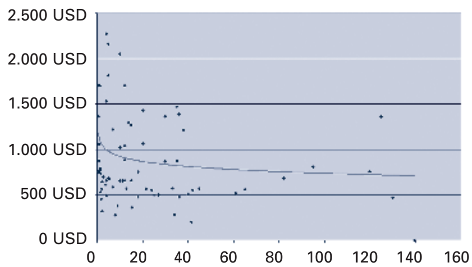


Picture 4_11: Costs of different sanitation options. Source: UNDP, 2006

Solutions such as VIP latrines and pit latrines are on the other end of the investment scale. Their safe application, however, is usually restricted to rural areas with low groundwater levels, in order to prevent negative effects on the environment and on public health.

The highest potential of DEWATS lies in peri-urban areas. Costs for the sewerage network of a centralised system can be up to five times higher than the sewage treatment plant itself. On-site DEWATS reduce sewerage network costs significantly. Furthermore, the cost of the treatment unit should also be lower, due to a less-sophisticated technical layout.





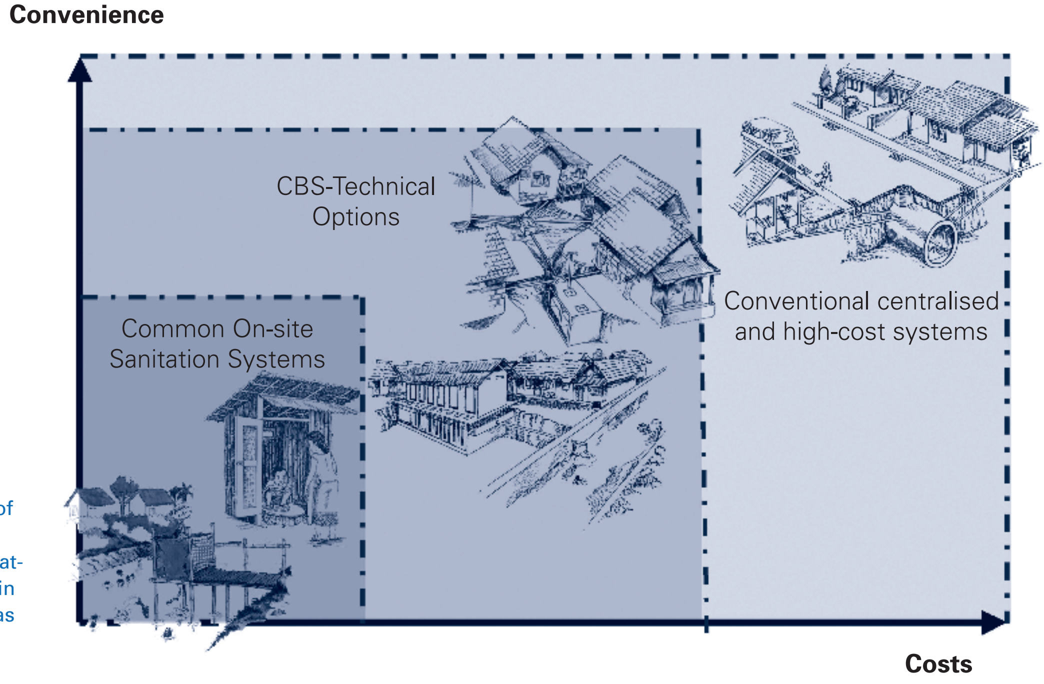
Picture 4_12: DEWATS, Indonesia: Initial investment costs vs. daily treatment capacity in m³

Picture 4_13: DEWATS, India: Initial investment costs vs. daily treatment capacity in m³

The exact cost of a DEWATS unit depends on the configuration of the system and the location. DEWATS are configured according to the desired treatment efficiency and various site-specific conditions. Since highest priority should be given to treatment efficiency and smooth handling of operation and maintenance, are recommeded ponds rather than tanks and tanks rather than filters.[22]

22 Additional parameters, such as insect breeding, may be considered as well.

However, the ever-increasing value of real estate – not only in city centres, but also in fast growing peri- and semi-urban areas – eliminates treatment ponds as a viable option, due to their large surface area demand. Intensive treatment in compact anaerobic digesters proves more cost-effective in many locations. Due to restricted land availability, DEWATS are frequently constructed as a series of settlers, baffled reactors or anaerobic filters, followed by constructed wetlands and polishing ponds.



Picture 4_14: Cost and Convenience – a comparison of sanitation and wastewater-treatment systems in peri-urban areas

A study carried out in India and Indonesia shows the relationship between the scale of a project and the required DEWATS investment costs (land, materials and construction). The cost per cubic metre of treated wastewater per day decreases significantly as the treatment capacity of the plant increases. The high variation of cost data within the study results mainly from varying property prices at different locations.

In comparing different wastewater-treatment options, a comprehensive financial analysis should consider the following:

- Investment in equipment and construction
- Price of the land
- Costs for financing
- Operation and maintenance cost

4.4.2 Economic analysis in times of global warming and energy scarcity

DEWATS' advantages over centralised systems become more apparent when external costs are included in the financial analysis. At a time of water scarcity, of rising energy prices and of global warming, decision-makers have to find their way through a multitude of important economic and ecological parameters. For example, most centralised systems rely on flush toilets, which contribute significantly to water consumption in urban areas and contribute to the deterioration of water resources. Particularly in regions of water scarcity, this leads to greater water stress and higher prices for fresh-water generation. Increased water usage reduces the natural recovery capacity of water-catchment areas and, thereby, increases the cost to the national economy, as more of its environmental assets are depleted. Furthermore, the energy need for water transport and wastewater treatment is far higher than commonly perceived.

Given the complexity of the issue, it is obvious that the discussion about sustainable energy and water use has just started. But there is evidence that such strategies have to consider the "real costs" of the use of resources. Incorporating "real costs" into water and energy prices will influence utilities and institutions in their search for the most cost-effective technological option. In particular, technologies permitting water reuse – as DEWATS do – may gain significant, comparative advantages. So, again, the need obvious becomes to take into account the external use of energy use once.

It is obvious that even more factors should be taken into account. As mentioned earlier, wastewater management plays an important role with regard to the sustainable use of water. According to the California Energy Commission, about 4% of California's demand for electricity is for the purpose of water transport and water treatment. Though such a figure might differ significantly from region to region and country to country, it is obvious that this electricity demand results in an important generation of CO^2 emissions. Therefore local water use and reuse systems can contribute to a significant decrease in the production of greenhouse gases and to reduced of energy costs – a factor that becomes more and more relevant with climbing energy prices.[23]

23 See: Perry L. McCarty: "Towards Sustainability – A Paradigm Shift in Concepts, Analyses, and Goals", presentation at WEFTEC, 2007

Perry L. McCarty did a comparative analysis of the energy costs of three treatment layouts in California.

- The first: a "traditional" aerobic treatment with incineration of the sludge
- The second: a "traditional" aerobic treatment followed by an anaerobic treatment
- The third: a stabilisation pond (algae) followed by anaerobic treatment

In this calculation it is taken into account that

- CO_2 emissions will be fined and
- that anaerobic digestion generates biogas as an energy source

This analysis shows that, with components such as "stabilisation ponds", a significant saving on energy costs can be achieved and – as long there is no significant anaerobic-digestion process – only comparatively of CO_2 emissions will be found. In the same way through the production of biogas, addition a income can be generated.

And wastewater itself represents about 1.3% of these emissions (CH4+N_2O Emissions -% of Total CO_2eq) mostly generated in septic tanks and sewer lines where the methane is not collected and burned. A point that should no longer be neglected is the fact that waste handling leads to greenhouse gas emissions.[24] Coming back to McCarty analysis: Where the methane/biogas is not used, the overall calculation and balance will look quite different.

24 See: Perry L. McCarty: "Towards Sustainability – A Paradigm Shift in Concepts, Analyses, and Goals", presentation at WEFTEC, 2007

Energy costs – US$ 1000/year Treatment of 10,000 kg BOD_5/day			
	Aerobic + Incineration	Aerobic + Digestion	Algae Digestion
Oxygen Supply	178	178	
CO_2 Penalty	58	24	12
Excess Power		299	378
Total	**236**	**97**	**366**
CO_2 penalty = US$ 20/tonC			

Table 6: Source: Perry L. Mc Carthy, 2007

The challenge is obvious: wastewater engineering and planning have to avoid the production of greenhouse gases or they have to ensure that the greenhouse gas is used. In the case of DEWATS, the generated biogas can be used for many purposes (see below). And apart from avoiding of negative impacts on the environment, the use of biogas can significantly improve the cost/benefit ratio of each system.

Picture: 4_15: Tombouctou, Mali. Not only in semi-arid regions: flush-based toilet systems are often economically and ecologically unsustainable

4.4.3 Economic considerations for single point polluters

Regional or urban planners may apply different economic-decision criteria than the owners of hospitals, small or medium enterprises, or residential estates, who are urged to find an efficient and cost-effective wastewater-treatment solution. While planners focus on the long-term overall development of a region, those running institutions a business are concerned with the compliance of legal-discharge standards, often at short notice. In these cases, decentralised wastewater treatment solutions are frequently the only option; so the most appropriate available option must be chosen. Decentralised treatment can be provided by:

- rotating, biological disc reactors
- trickling filters
- activated sludge processes
- fluidised bed reactors
- sequencing batch reactors
- or DEWATS, as described in this book

Picture 4_16
Many high-tech wastewater-treatment systems function inefficiently because it's not possible to have qualified staff to operate and maintain them

Since DEWATS are based on simple technology, which requires minimal operation and maintenance, they are favourable with regard to investment and running costs. Other technologies may require continuous support by qualified staff – oftentimes this is neither available nor affordable.

In theory, sound economic analysis requires comparable data about the various systems to be compared. In reality, the specific site conditions and the priorities of the decision-makers prevent the formulation of a standardised comparison and decision process. Every site requires its own assessment.

At the very least, the following parameters should be considered:
- potential for reduction of wastewater quantity
- potential for reduction of pollution load
- geography, geology and topography
- space availability
- availability of qualified staff for the required tasks
- discharge standards
- social environment and neighbourhood

Depending on the situation, the final decision usually has a strong socio-economic bias:

> "It has been shown that, under certain local circumstances, large variations in economy are to be expected, but the general conclusion (...) is that the economy of the various treatment processes does not differ that much. In many cases the costs are approximately the same. This increases the importance of those factors which cannot be included in an economic survey. Some of these factors are limiting factors in the sense that they limit the "free" selection between the various methods. If large areas of land are not available, then oxidation ponds must be disregarded even if it is the most economically favourable solution. If electricity supply is unreliable, then activated sludge systems cannot be considered. (...) It can be argued that the factors mentioned above are purely economic in nature, e.g. a reliable electricity supply is merely (!) a matter of economy. However, the costs involved in changing these factors to non-limiting factors are so high that there is no point in including such considerations here."[25]

25 The Danish Academy of Technical Sciences: industrial wastewater treatment in developing countries, 1984

4.4.4 Parameters for economic calculation

Wastewater-treatment systems, in general are not implemented to generate income. Although valuable by-products are created, such as biogas as a renewable-energy source, sludge as an organic fertiliser, or recycled water for the reduction of overall fresh-water consumption, wastewater-treatment systems are primarily infrastructural services, which must be financed by public/private bodies or individuals.

As the price of natural resources, such as oil or phosphorus, continues to increase, the valuable by-products of wastewater-treatment units will begin to play a greater role. In most cases, these products currently do not generate enough return to reach a financial break-even point. However, new macro-economic tools, like regulations that promote electricity supply to the grid and new power generating technologies, are beginning to affect the market. Significant returns should be possible at sites with intensive animal husbandry in the very near future. As a general rule of thumb, however, classical cost-benefit analysis does not fit the economy of wastewater treatment – yet.

The annual cost method appears to be a more apt economic indicator. It creates a more comprehensive picture of the economic implications by factoring depreciation on capital investment and operational costs into the calculation. Expenses to the polluter, like discharge fees, or income from the reuse of by-products are analysed on an annual basis. A spreadsheet for computerised calculations is presented in chapter 10.

Picture 4_17: The integration of DEWATS into the infrastructure – here is a parking lot in Java – can reduce investment costs

Cost of land

Data about the cost of land may be essential when comparing different treatment systems. The applicability of sand filters or ponds is affected more by the price of land than the applicability of compact anaerobic digesters; where land prices are high, compact tanks – not ponds or filters – will be the natural choice. The value of real estate can vary widely, depending on the location. In some cases, it may contribute up to 80% of the investment cost.

Construction costs

Annual costs are influenced by the lifetime of the hardware. It may be assumed that the building and ground structures have a lifetime of 20 years, while filter media, most pipelines, manhole covers, etc. are only likely to last for 10 years. Other equipment, such as valves, gas pipes, etc., remains durable for six years. All structural elements should be categorised into one of these three categories.

Picture 4_18: DEWATS are quality products – planning and monitoring of implementation must be carried out by experienced staff

It is assumed that full planning costs will reoccur at the end of the lifetime of the main structure, i.e. in about 20 years. In any individual case, the costs of planning can be estimated. Costing will be carried out by an local experienced engineering team. Designing and supervising the implementation of DEWATS used for. Due to the relatively high-quality requirements of decentralised systems, engineering costs are likely to be relatively high. Besides, other labour costs plus laboratory cost for the initial testing of unknown wastewaters must also be included.

Table 7:
Materials required to construct DEWATS to treat the wastewater of approximately 1000 people (sewage production per day 80.000 litres)

	Items of work	Unit	Quantity
1	Earth work, excavation for baffled reactor	m^3	478.40
2	P.C.C, 10 cm thickness, floor of the tank	m^3	23.92
3	Sand filling, 10 cm thickness	m^3	23.92
4	RCC vertical slabs for outer walls, internal partition walls	m^3	70.65
5	R.C.C, cover slab, 15 cm thickness	m^3	23.23
6	Plastering inside the baffled reactor using 1:4 mortar	m^3	1078.00
7	Pre-cast ferrocement baffle walls, 3 cm thickness with necessary brick pins	m^3	236.87
8	Supplying and fixing 6-inch pipes for inlet & outlet	m	12.00
9	Supplying and fixing 6-inch T-pipes	no	4.00
10	Filter media for anaerobic filters	m^3	18.50
11	Manhole, size: 450 mm x 450 mm	no	15.00
12	Manhole, size: 600 mm x 600 mm	no	2.00
13	Filter drains for reusing treated water for irrigation	m^3	200.00

Running costs

Running expenses include the cost of personnel for operation, maintenance and management, including monitoring. Cost is based on the amount of time needed for qualified staff (including staff trained on the job) to attend to the plant. The time required for plant operation is normally assessed on a weekly basis. If inspection and attendance are covered by permanent staff, cost calculation is simple. Special services, requiring external work force, incur additional costs. Shared facilities, created by attaching 5 to 10 households to one DEWATS, are likely to be 10% cheaper than individual plants. In such a case, operational responsibility must be clearly defined to ensure reliable maintenance and sustainable operation. Open systems, such as ponds or constructed wetlands, require more regular attendance than closed systems, as they may be damaged or disturbed by animals, stormy weather or falling leaves. The cost for desludging and sludge treatment will, be higher however, for heavily loaded tanks than for ponds, which receive only pre-treated wastewater.

Picture 4_19: Service vehicle in Vietnam – desludging costs are important for financial analysis

Additional benefits from wastewater treatment

The market value of wastewater treatment by-products can be estimated by calculating the price of the products that they substitute.

Especially in dry regions, water is a major cost factor for consumers. Recycling DEWATS-treated wastewater, therefore, may considerably reduce the water bills of private consumers, companies and other entities. As described in chapter "good practices", the Aravind Eye Hospital in Pondicherry, India reuses 308 m³ of its daily treated wastewater for gardening purposes, while the Bangalore-based Alternative Food Ltd. feeds a major part of its daily treated 28 m³ of wastewater back to its production processes.

Biogas has an economic value as a renewable-energy source, which can substitute other fuels. Approximately 200 litres of usable biogas are produced per kilogram of removed COD. The actual gas production equals 350 litres of methane (500 litres of biogas) per kilogram total BOD; however, a part of the biogas remains dissolved in water, especially at low wastewater strength. Biogas contains 60 to 70% methane. One cubic metre of methane is equivalent to approximately 0.85 litres of kerosene.

To allow biogas utilisation, the structure must be gas-tight and additional volume must be provided for storage. Pipes and valves are required to transport the gas to the place of consumption. The cost of operational and maintenance attendance is likely to be approximately 50% higher if biogas is used. Further additional investments enabling the use of biogas include, approximately, 5% to the cost of long-lasting structures (20 years, lifetime), another 30% to the cost of internal structures (10 years, lifetime) and an additional 100% of the cost of equipment (6 years, lifetime). The finance costs of the additional investment must also be considered.

If the use of biogas proves to be too costly or complicated, capturing and direct burning (without use) should be considered for environmental reasons. The gases created in the wastewater-treatment process contribute significantly to global warming. Torching reduces the negative impact on the environment and, therefore, is recommended if financially viable.

Picture 4_20: Aravind Eye Hospital reduces its water bill significantly by sensing treatment wastewater

Picture 4_21: Modern rice boiler – the use of biogas is not only of interest as a way of creating return; it should be mandatory for ecological reasons

Treated wastewater can also be used to generate through income agricultural production or fish-farming. Knowledge about the size and management of the farm, as well as an assessment of the market for selling the products, will assist in making economic predictions. Experience has shown, however, that exact predictions are difficult to make.

Capital costs

If investment capital is borrowed from a bank, direct capital costs – in the form of interest – must be paid. On the contrary, if one's own money is invested, the cost of this capital is indirect because it could be used in other profitable ways (purchase of raw material for production, investment in shares or bank deposits, etc.).

For calculation purposes, annual capital costs of 8 to 15% of the investment can be assumed, depending on location and current economic-market developments.

Picture 4_22: Floriculture in China – slurry from bio-digesters is a resource for organic farming

4.4.5 Sustainable financing schemes for sanitation programmes

4.4.5.1 Multi-source funding for poorer areas

At single pollution spots, like small and medium enterprises, hospitals, etc., wastewater treatment may be financed exclusively by the polluter – with or without subsidies or credit lines. Generally, however, sanitation and wastewater treatment must be viewed as a service provision, similar to water and electricity supply. Comprehensive analysis of local conditions is necessary to develop reliable financing schemes for residential areas.

The economic situation of the users plays a large role in the determination of applicable financing schemes. In industrialised countries, sanitation services are in most cases, paid for by the users themselves (in-house toilets are paid for directly, sewage lines and treatment systems are paid for through fee and tax systems). In most developing countries, however, large sections of the population cannot afford to participate in a full-cost coverage system. So the question arises: to what extent are users able to participate financially, and what alternative cost-recovery systems can be applied?

The World Bank promotes the following financing schemes for improvements in the sanitation sector:

- "Households pay the bulk of the cost incurred in providing on-site facilities, including on-site sewer connections
- Residents of a block collectively pay the additional cost incurred in collecting wastes from individual houses and transporting these to the boundary of the block
- Residents of a neighbourhood collectively pay the additional cost incurred in collecting wastes from blocks and transporting these to the boundary of the neighbourhood
- Residents of a city collectively pay the additional cost incurred in collecting wastes from blocks and neighbourhoods and transporting these to the boundary of the city or treating it in the city"[26]

26 Source: www.irc.nl/page/6456

Full-cost coverage should be achieved in residential areas with higher income levels. In poorer areas this cannot be expected, as surveys frequently indicate that "sanitation" is rather low on residents' priority lists for spending. At the same time, 100 per cent of charity driven approaches have failed repeatedly in the past; A substantial contributions from users, therefore, is perceived as an indicator for community appreciation of the project and should be considered a "must" for successful sanitation programmes, even if the contribution covers only a small fraction of the total cost. No sanitation activities without a substantial contribution by users!!

The local situation and relevant financial-boundary conditions of all stakeholders must be assessed to determine the appropriate contribution levels for the poorer member of the population. In dealing with sanitation issues, public decision-makers must achieve balance between social-equity issues and their financial constraints. Sanitation and wastewater-treatment services can be provided through multi-source financing, based on recovering costs from users and from public sources from local, regional and central governments and/or international donor organisations.

Alternatively, good experience has also been gathered in projects, where well-off areas cross-subsidised their poorer counterparts. No matter which approach is favoured, financial schemes should always focus on the long-term perspective, to ensure sustainable operation of the sanitation and wastewater-treatment systems.

The following elements are essential in the development of a financial scheme for a sanitation programme:

- Assessment of available public and private funds, users' economic status, willingness to pay, etc.
- Technical feasibility study – identification and analysis of different layouts for sanitation and wastewater-treatment facilities
- Calculation of overall project costs, including operation and maintenance – based on experience from pilot projects and/or preliminary tendering
- Informed-choice assessment of different long-term, multi-source financing schemes – resulting in development of financing mechanisms and definition of user fees

Sound financial planning must take not only the initial investments into account, but also the long-term costs of continuous operation!

Sanitation programmes must gain the acceptance of the user; without user acceptance any financial scheme will fail. Users must express a definitive "willingness to pay" to guarantee sustainability. Experience shows that "willingness to pay" is oftentimes to amounts, perceived by the user as benefiting them and inline with their priorities. In many cases, studies to determine the "willingness to pay" show that users in weak economic situations are not willing and/or not in the position to pay for wastewater treatment (sewage systems and wastewater-treatment units). Substantial contributions by users are mandatory, even in poorer areas. Here, however, the fees collected will cover only a minor part of the total costs.

Picture 4_23: In developing financial schemes, sanitation and wastewater treatment should be viewed as a service provision, comparable to energy and water supply

Picture 4_24: Residential areas with high income levels should achieve full-cost coverage for sanitation and ideally assist in cross-subsidising poorer areas

Besides this problem, providers of sanitation and wastewater-treatment services face an additional challenge: unlike water and electricity supply, the service cannot be cut off if users refuse to pay. Once sanitation and wastewater equipment has been installed, few sanction mechanisms exist; users will find other ways to dispose of their waste – with consequences for the whole community.

Picture 4_25: Community Sanitation Centre in Bali, Indonesia – unlike water and energy supply, sanitation service provision has few mechanisms for making users pay

The profile of each CBS (Community-Based Sanitation) programme has to be country, site and situation specific. Nevertheless, in this chapter we will introduce the core elements of successful CBS implementation. The outlined programme-implementation steps are based on the project experience of "good practice" examples and guide the reader through his or her own programme and project development.

5 CBS programme planning and implementation

The institutional background has a significant impact on programme initiation. While organisations experienced in infrastructural development in poor areas might be able to develop institutional capacities fairly rapidly, other organisations might depend on the collaboration with other institutional players. In such a case, the greatest challenge will be to streamline the process and contributions of all partners.

The goal of any sanitation programme should be long-term sustainability with maximum positive impact. From the preliminary needs assessment in the very early stage of a programme, up to the disposal and treatment of sludge, a multitude of tasks have to be completed. The efficient setting-up and implementation of such a programme requires early identification of the different necessary tasks and who is responsible for carrying them out.

5.1 Stakeholders in CBS programmes

Sustainable infrastructure development and sanitation programmes must co-ordinate and streamline a multitude of stakeholders and resources. The active participation of different parties should span the entire development process, from the preparation phase, to planning, implementation, monitoring, and final evaluation. Participation improves the sustainability and performance of the project. Ownership ensures stakeholder commitment and participation, thereby reducing supervision costs.

Efficient, cost-effective and sustainable implementation requires systematic involvement of different stakeholder groups:

- Primary stakeholders – residents and direct users of the implemented measures
- Secondary stakeholders – groups with a direct or indirect responsibility in the programme. These include the leading agencies (public, NGOs, etc.), planning authorities, and health and environmental departments.
- Tertiary stakeholders – providers of special services for construction, main-tenance and sludge management.

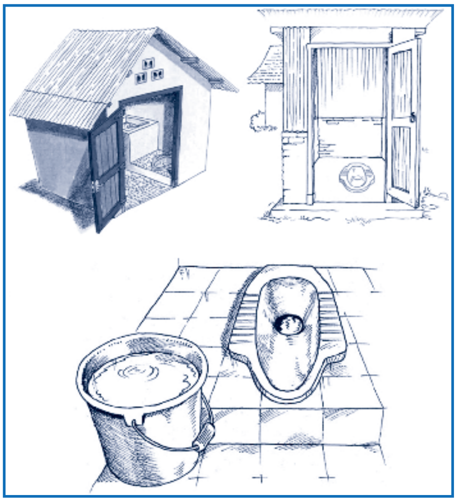
5.2 Responding to basic needs – active involvement of beneficiaries and residents

CBS programmes respond to the needs of a given area's residents. In most cases, the programmes target residents of poorer areas to provide them with improved in-house toilets or with additional sanitation services, such as showers or washrooms in Community Sanitation Centres.

The active involvement of communities in the planning and implementation process is crucial to the success of a sanitation programme because the residents

- will use the sanitation facility – the facilities must fit their needs and practices
- have to contribute significantly to the system – financially or in kind
- may have an important role in the operation and maintenance of the sanitation and wastewater-treatment facilities.

Picture 5_1:
CBS programmes should respond to resident needs



Picture 5_2:
Sanitation program–mes should offer different options for improved sanitation facilities – here a pour-flush toilet

To ensure that poor residents are actively involved, the following factors are important:

- Sanitation programmes should be accompanied by health and hygiene awareness-raising campaigns
- Programme acceptance by local leaders helps to avoid unnecessary interference with social hierarchies
- Social-settlement structure and stratification, sanitation practices, informal land-holding customs, and reservations about infrastructure implementation should be understood and taken into account
- Women are often the household decision-makers with regard to domestic sanitation and sanitation practice. Therefore, they must be actively involved in determining problems, identifying underlying causes, recommending possible solutions and ultimately, making decisions to solve the problems

Developed over recent years, "demand-responsive approaches" have become the conceptual framework of sustainable sanitation programmes. The approach treats users as clients, who express their needs, but must provide contributions in monetary terms or in kind.

Neither "demand" nor "willingness to pay" are easily measurable. Comprehensive methods have been developed to cater to users' needs: "informed choice" generates indicators for communities' and individuals' willingness to participate in the project. "Contingent valuation" (CV) provides information on potential demand and willingness to pay for different sanitation options.[27]

27 See: UNDP, *Willing to pay but unable to charge,* 1999

Depending on the location, "demand-responsive approaches" can result in quite different technical solutions and management configurations:

- In most parts of Eastern Java, coherent social structures mean there is a high capacity for community self-organisation and management. Decision-making processes, concerning the choice of sanitation facilities and the layout of the DEWATS, can be initiated by external facilitators and tend to run smoothly. the On the whole the community manages cost recovery, operation and maintenance. Only desludging is organised by an external service provider

- In Tangerang, Indonesia, the involvement of future users in the planning process showed not only the residents' interest in improved sanitation but also in shower and laundry facilities. As the residents are mainly migrant workers, social structures are rather weak. To ensure sustainable management of the sanitation project, it was decided that BEST, a local NGO, should function as service provider. BEST ensures daily operation, maintenance and desludging of the system. The costs are covered by a fee that residents pay when they use the facility
- In Ullalu Upanagara, Bangalore, a slum with inherent social frictions, an operation and maintenance system run by the community, was set up. The Community Based Sanitation programme was facilitated by the local NGO. Strong emphasis was put on the involvement of women in the awareness-building process for sanitation demand. One of the women, groups later took over the operation and maintenance of the Sanitation Centre. Users pay a fee per use. Desludging is organised in co-operation with local government
- Although categories like "available income", "existing sanitation facilities" and "hygienic behaviour" are important parameters for a comprehensive assessment, "willingness to pay" is one of the strongest indicators. In a slum area of Mysore, India, a range of low-budget sanitation options were discussed with the residents. The potential users were only willing to pay a very small amount for the most-desired facility, a 20-toilet sanitation centre. It was only through the intervention of an experienced facilitator their it became clear that the residents had a long-term vision – for each house to be supplied with an in-house toilet. Although this was a very expensive option, they were prepared to contribute much more towards this solution. The sanitation centre would probably not been acceptable in the long term

The following suggestions may help successful collaboration in poorer residential areas:

- Residents must contribute to the programme financially or in kind. However, there is no blueprint for how much must be contributed to a CBS programme. The "contribution profile" must be developed in accordance with the local social situation and the interests of the residents
- Participation needs time and resources; it is essentially a process with there no guaranteed outcome. For these reasons, the financial cost of participation has to be carefully weighed against its benefits. A reasonable balance between input and output should be achieved
- CBS may interfere with the social structures of a community. Under certain conditions, participation can have a destabilising effect by creating an imbalance in existing socio-political relationships. Participatory approaches can result in conflict because existing power relationships are threatened. A sensitive approach is vital to avoid worsening the position of those who are already marginalised
- A fact-driven approach is suggested. Although the residents of poor areas must be provided with basic-needs services, an exaggerated emphatic approach may result in skewed perception of ground realities and a CBS program with too much "wishful thinking"

Picture 5_3:
In Tangerang, residents have to pay the equivalent of 0.06 Euro for each time they use the facility. The service provider employs one operator, who ensures operation and maintenance

Picture 5_4:
In Ullalu Upanagara, local women were trained to ensure continuous operation

5.3 Local government and municipality bodies

Local public bodies play a pivotal role in successful sanitation and wastewater-treatment projects. Although the specific responsibilities of a body may vary from country to country, it is the local government (or municipality) that is usually accountable for providing sanitation and wastewater-treatment services. Furthermore, it is also responsibile for promoting health and hygiene awareness, to ensure the health of its communities and to monitor the environmental impacts.

Local government and municipalities should formulate and implement a policy addressing the sanitation backlog and water-pollution problems. They are responsible for driving the local processes set out in its policy. They must create an enabling regulatory environment through municipal by-laws – and ensure both appropriate and affordable service implementation. Furthermore, the local government must ensure that environmental standards are met, including the establishment of a system for sludge removal, treatment and disposal.

In an ideal world, local-government agencies would integrate sanitation and wastewater strategies into their local development plans and take the lead in them implementating. In the real world, different stakeholders may take the initiative to provide sanitation services, particularly to the poor. Beside public bodies, international agencies, NGOs and Community-Based Organisations may be active. In such cases, the of a co-ordinated strategic alliance between different stakeholders can create a greater drive for the implementation of efficient sanitation and wastewater-treatment options. Nevertheless, local government and municipalities must be fully involved.

To assist the implementation of wastewater-treatment infrastructure, the relevant bodies should:

- create a demand for sanitation improvement through health and hygiene-awareness programmes
- respond to this demand by identifying of appropriate sanitation options
- prioritise these options
- integrate these working results into a planning process
- allocate funds to achieve the planned objectives
- ensure there are enough appropnately skilled people to carry out the plan
- implement the plan
- monitor and report on the results and
- ensure sustainability

Picture 5_5: Strategic alliances between different stakeholders ease CBS programme implementation

5.4 Non-governmental organisations

A number of NGOs have launched CBS programmes and/or have become programme partners to government bodies. Which roles NGOs play within CBS programmes depends mainly on their competencies and the local situation.

NGOs can play a leading role in CBS programs. As specialists in poverty alleviation and environmental protection, many NGOs have in-depth knowledge about the low-income groups with whom they work. They know about local sanitation practices, decision-making processes within the communities, income and expenditure patterns, and other factors, crucial to successful sanitation programme implementation.

Furthermore, many NGOs have good functioning working relationships with the communities. So they can facilitate awareness-raising campaigns, decision-making processes or other forms of communication.

Over time, many NGOs have developed competencies as service providers. Some are active in the fields of solid-waste management, environmental counselling and/or urban planning. Other NGOs have the capacity to set up and run complete sanitation and wastewater-treatment projects, including the provision of operation and maintenance services.

5.5 Private sector

In most cases, the private sector can and should cover important CBS program tasks. The private sector may:
- plan, design and construct sanitation infrastructure
- plan, design and construct wastewater-treatment infrastructure
- manufacture equipment
- ensure operation and maintenance of the overall scheme
- operate desludging and sludge-treatment facilities

These services may be provided on a contractual basis. Close quality monitoring of the delivered services is crucial to the sustainability of the programme.

6 CBS programme – detailed procedure for implementation

6.1 First planning activities

The success of a CBS programme depends significantly on implementing the steps in the right order. The organisation or the group of initiating bodies, taking the lead in launching a project should be aware of the complexity and usefulness of a comprehensive approach. Success depends on the co-ordinated implementation of a multitude of tasks and the integration of all stakeholders into the process.

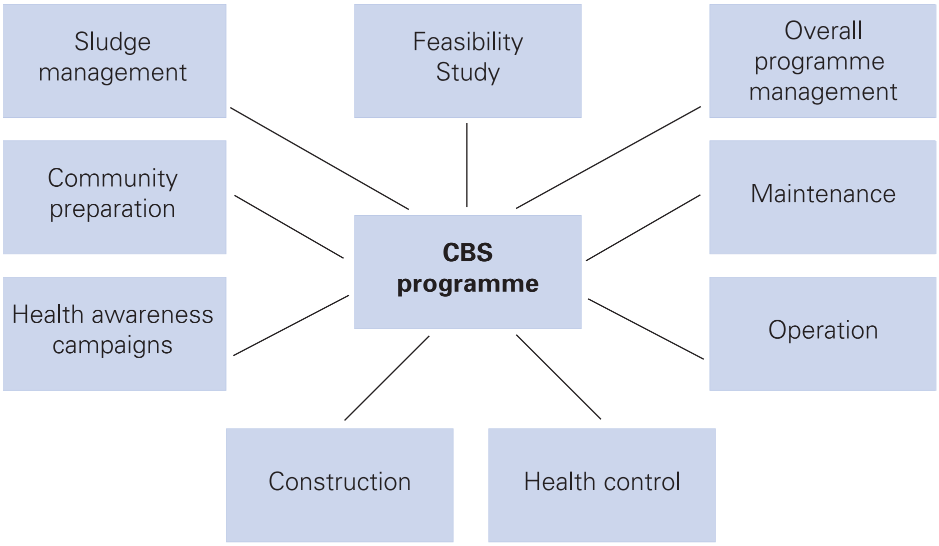
Picture 6_1: Stakeholder roles and responsibilities must be clearly defined at an early stage – CBS programme steps should be understood by everyone

An initial workshop helps to establish a common foundation between key stakeholders. Members from the leading agency (LA), NGOs – or representatives from future beneficiary groups – should be invited to form a core team. The following issues should be addressed:

- targets of the envisaged programme
- assessment of the current situation in the relevant area, regarding sanitation and wastewater
- key existing problems sanitation, wastewater and environmental pollution
- existing experiences with relevant projects
- awareness building concerning the tasks to be fulfilled throughout the programme
- identification of relevant stakeholders to involve in the project

The key programme tasks should be identified at an early stage. With these in mind, the steps of implementation should be defined to enable smooth operation. Key tasks include:

- overall programme management, including process monitoring
- developing a feasibility study
- community preparation, including health and hygiene awareness-raising campaigns
- construction
- operation and maintenance
- monitoring sanitation and environmental standards
- final sludge management

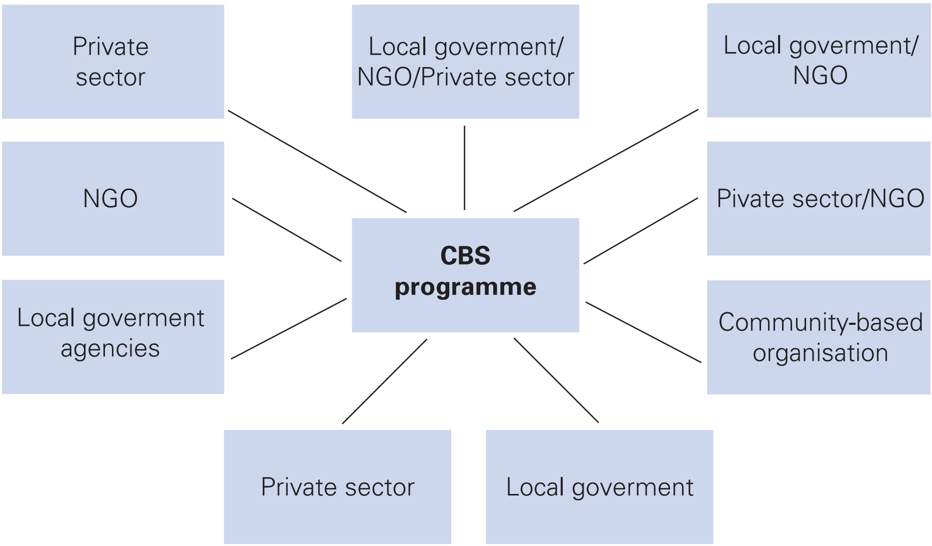


Picture 6_2:
CBS programme – core tasks

Workshop participants should identify the specific competences and resources of the various stakeholders. Their roles and main responsibilities within the programme should be assigned. The collaboration and roles of partners may vary greatly from location to location.

Furthermore, the workshop should help to establish an efficient working structure. In particular, the role of the leading agency should become clear, including its core management and monitoring responsibilities. Questions to be answered include:

- What are the tasks and responsibilities of the leading agency?
- What roles and responsibilities can the communities fulfil?
- In what areas can the private sector contribute to achieve higher quality and cost effectiveness?
- What competencies can other stakeholders, such as government agencies or NGOs, contribute?
- Which tasks cannot be fulfilled by the available stakeholders? Which measures, including staff recruitment, are needed to bridge the existing gaps?



Picture 6_3: CBS programme – stakeholders

The signing of a contractual agreement or Memorandums of Understanding between the stakeholders at an early stage in the programme helps to establish a solid foundation for the following steps of co-operation.

6.2 The pilot project

Setting up a large programme is facilitated by a successful pilot project. Experience shows that it is better to implement a simple pilot, which can be extended, than to be too ambitious and create a complex programme that cannot be handled by the implementation body.

A pilot project should:
- clarify and strengthen the working structure of the implementing body
- provide all stakeholders with a firm understanding of the challenges and technical, social and financial requirements for an implementation programme
- elaborate and test appropriate instruments and tools for large-scale application
- integrate the relevant stakeholders into the implementation process
- equip executing bodies to be constructors for further activities
- create standardised procedures for the overall approach

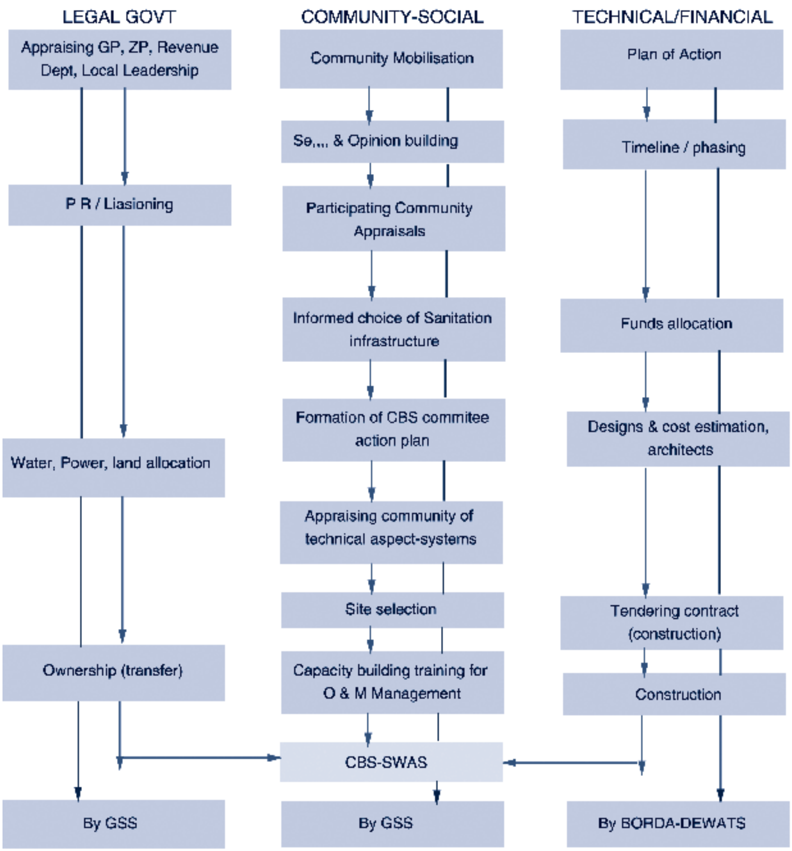
The location of a pilot project should be representative of other local locations in the municipal area, with regard to quantity and quality of wastewater, socio-economic structure, settlement layout, etc. It should also allow for fairly smooth implementation and operation to set a positive example.

The CBS programme in Ullalu Upanagara, Bangalore, India, for example, was used to test the implementation procedure. The experience gained from the project was later used to effectively target other sites within the programme area.

A pilot project provides valuable information for future projects within the programme:
- Which feasibility-study parameters are relevant in different parts of the city?
- Which planning tools are most efficient?
- How should a demand-responsive approach look for similar target groups?
- Which DEWATS configurations would be most appropriate at similar sites?
- Which informed-choice options proved most useful?
- Which stakeholders must be involved in which implementation stages?
- Which public authorities are relevant for overall project clearance?
- Which "informal leaders" must be involved?

- How can women be targeted through special awareness-raising campaigns?
- Which problems are likely to emerge (i.e. with land-holding)?
- Which contractual arrangements with which stakeholders proved most useful?
- How can the overall implementation process be monitored?
- What financial and in-kind contribution can be expected from the users?
- How can operation and maintenance be organised?
- What can be expected from the users and which tasks must be fulfilled by a service provider?

Evaluating a pilot project helps to optimise future planning processes.



Picture 6_4: Chart indicating the implementation process in Ullalu Upanagara

6.3 Preparation phase

6.3.1 Kick-off workshop

Experience shows that it is beneficial to officially launch the programme with a "kick-off" workshop to which the various stakeholders are invited:

- senior government officials at the local, regional and national levels
- relevant NGOs
- representatives of the target groups
- relevant researchers
- private-sector participants
- international agencies
- media, etc.

Picture 6_5:
The kick-off workshop introduces the scope of the programme and involves senior stakeholders on various levels

The workshop should:
- communicate the results of the pilot project
- demonstrate the scope and relevance of sanitation and wastewater-treatment programmes in relation to different fields of policy and different government levels
- clarify the importance of target driven co-operation between stakeholders

The workshop is aimed at:
- creating awareness amongst decision-makers about the legal requirements, required resources and institutional backing for the programme
- developing a supportive environment – getting different stakeholders and local authorities to offer their competencies to the programme
- launching a process for the provision of financial and human resources on different government levels
- gaining support for extending the programme into other municipalities, departments, or provinces

6.3.2 Planning workshop

The planning, implementation and monitoring activities of a programme should be launched at a planning workshop. The workshop participants analyse the results of the pilot project and draw conclusions for dissemination on a larger scale. The main out-comes of the workshop might include:
- formulation of stakeholder responsibilities, timeline and resource planning
- standardisation of procedures, such as site selection, community involvement, tendering, construction, sludge management, etc.
- drafting supporting documents, such as training kits, contract forms, monitoring sheets, etc.
- formulation of capacity-building plan for key stakeholder groups

Participants of the workshop should be:

- local authorities
- NGOs
- members of the target group
- relevant private-sector participants

Ideally, the workshop results in an approval agreement between the stakeholders involved in the implementation of the programme. Discussing and agreeing on responsibilities and the stages of the project in advance helps to avoid conflict during the later stages of implementation or operation.
Other criteria, which may be useful, include:

- health risks within the area
- vulnerability of the ecological system or possible environmental threats
- legal status of the settlement
- income classification

Picture 6_6: Clear agreements between project partners ease the implementation process

The long-listed communities should be assessed and ranked. To enable comparison, the following information should be collected:

- current situation of sanitation and wastewater treatment
- reports on existing sanitation programmes in comparable areas
- indicators for the community's willingness to participate in a program
- social structure and decision-making procedures within the community
- legal status of the settlement
- land availability
- geological and topographical data

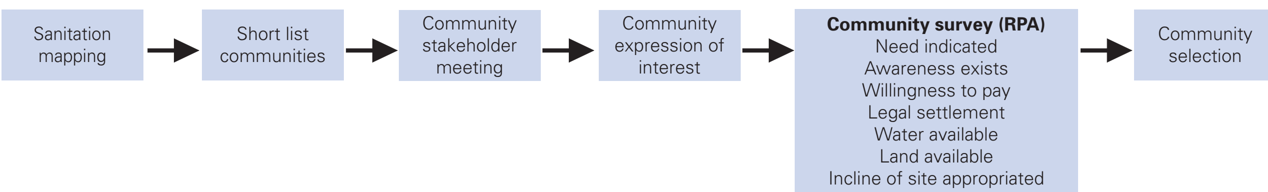
The community is provided with information about CBS and invited to a stakeholder meeting. The meeting agenda should be adapted to the specific local context. During the meeting, the CBS programme is presented and the sanitation conditions in participating communities are discussed. The contributions expected from the community must be stated clearly. Interested communities are asked to submit an expression of interest (EoI) in taking part. The EoI includes an invitation for a rapid participatory assessment (RPA).

The RPA determines if the site is suitable for DEWATS applications:

- Natural gravity flow should be assured – the natural slope of the land should lead the wastewater from where it is generated to the treatment plant and then to the discharge point
- Availability of water and land for construction are essential for DEWATS implementation. Illegal settlements are excluded from participation. If an area is prone to flooding, community sanitation centres are usually recommended.
- Community sanitation centres require vacant land for construction. Land availability and ownership must be clear
- As sanitation and wastewater systems often have a negative image, residents living close to the planned CBS or treatment unit must agree to the chosen location. Planning procedures must take account of the time necessary for obtaining community acceptance of the facilities in their immediate neighbourhood

To make sure results objective are, representatives of all community stakeholder groups should be represented during the RPA process. The following RPA tools can be applied:

- Ladder – assessing community willingness to contribute to the new sanitation infrastructure
- Transect Walk – identifying and analysing the condition of existing sanitation systems in the neighbourhood through direct observation
- Problem Trees – identifying and analysing community sanitation problems, their cause and effect, and whether the community intends to improve its sanitation conditions
- Timeline – identifying and analysing residents' experiences with previous community-participative infrastructure projects.
- Venn diagram – identifying and studying existing local community institutions, their benefits and their relationship with the community. This tool is also used to assess community readiness to operate the facility



Picture 6_7: Flow chart: from sanitation mapping to community selection

6.4 Planning phase

6.4.1 Site assessment

Successful CBS planning depends on a detailed technical survey carried out by technical experts. The relevant information can come from local government and community surveys. Government authorities and stakeholders ,therfore, should on the ground be involved in the process. Some of the necessary information can also be obtained from the Rapid Participatory Assessment carried out during community selection.

Picture 6_8: Detailed knowledge of the local situation is the basis for appropriate planning

The technical survey procedure is identical, whith or without community participation. However, the process differs according to the selection of technology. Household-based sanitation systems, including simplified sewerage or off-site treatment, demand more complex surveys, planning and establishment activities than community sanitation centres with on-site treatment. The technical survey consists of four sections:

1. Assessment of general site conditions

- cartographic and topographic surveys and mapping – focused on settlement structure, topography (elevation) and site accessibility
- location and general data collection about local industries and enterprises, including home working, peripheral farming activities, restaurants and food stalls
- assessment of the number of potential users and their habits regarding water, sanitation and waste-related subjects
- survey of soil conditions at potential construction sites

2. Assessment of water and wastewater-related subjects

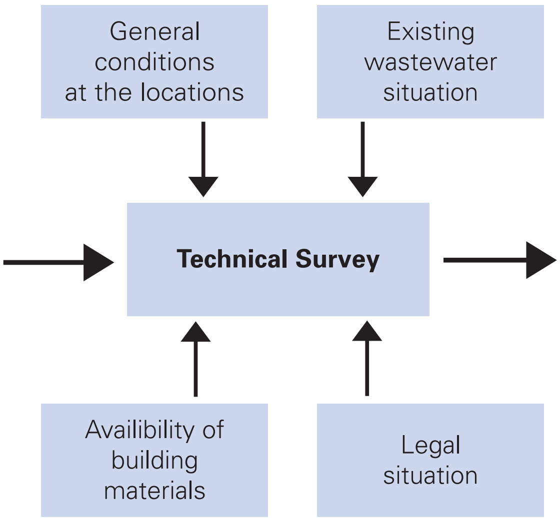
- assessment of water sources, including quantitative and qualitative security
- assessment of water-consumption levels of industries and households, and required quality for different uses
- assessment of domestic and industrial wastewater-generation processes, volumes, composition, discharge patterns and reuse options
- assessment of existing sanitation and wastewater-treatment systems – applied technologies, performance, responsibility for operation and management
- assessment of the rainwater-runoff infrastructure
- assessment of discharge options – survey of local water bodies with regard to quality, flow volume and location, including groundwater quality, use and level
- gathering of precipitation data for different times of the year

3. Legal background on wastewater

- gathering of wastewater-discharge standards and environmental-protection regulations

4. Building materials and tools

- assessment of local availability of building materials and tools



Picture 6_9: Technical survey

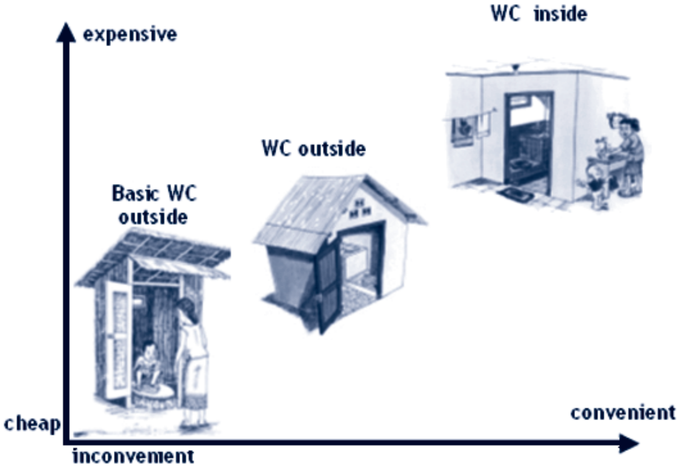
6.4.2 Informed technology choice

By providing the potential users with different options for sanitation facilities and services, the principle of "more expensive systems will cost more" is communicated. The users themselves can eliminate options that do not apply to their situation.

In the informed-choice process, users learn about many possible options:
- different toilet types and layouts of toilet facilities
- different functions and layouts of community sanitation centres
- different services levels to be expected

Informed choice is usually focused on the users' preferences concerning sanitation equipment. However, the following components can also be addressed within community meetings to assess the public acceptance of their application:

- sewer layout
- treatment components
- disposal or reuse of effluent
- disposal or reuse of effluent sludge



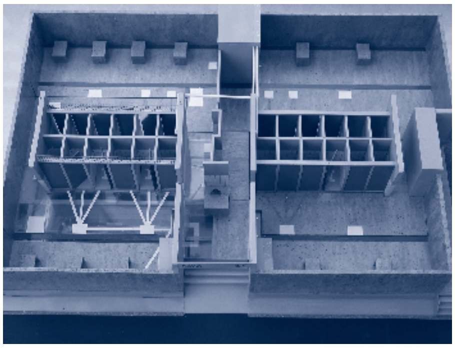
Picture 6_10:
Toilet-facilities options

Picture 6_11:
Experienced experts should facilitate assessments on willingness to pay and informed choice – substantial financial contributions by the users is crucial to the sustainability of sanitation schemes

6.4.3 Detailed engineering design

Experienced prepare technical experts, the detailed engineering design applying the results obtained from the technical survey, the technology-choice discussions and the assessment of other local factors at the design process. The solutions should be discussed with local decision-makers and community leaders – identify potential problems – stages of.

The superstructure of CSCs *can* be constructed with standardised designs. But, public acceptance will increase significantly if the users get to habe their say. The number of toilets, showers, water points and laundry places is calculated in accordance with the estimated number of users.



Picture 6_12:
The design should take into account the specific local conditions and the super preferences

Picture 6_13:
Experienced technical experts prepare the design

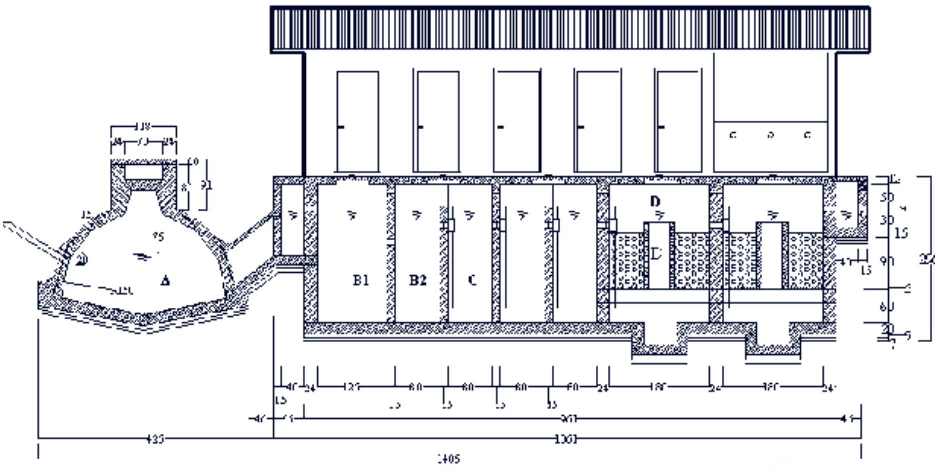
For in-house sanitation, the appropriate location for toilets, showers and wash-basins is determined together with the users. The sewerage system, including inspection chambers, must be designed according to the flow volume, peak flows and slope.

The most appropriate discharge or reuse option is selected and designed in accordance with possible applications, the local surroundings, the legal situation – and the treatment efficiency of the chosen technology.

The connection of small home-industries (e.g. tofu production), restaurants or food stalls can have a strong impact on the performance of the system. Where a simplified sewerage system with off-site treatment is constructed, special attention must be paid, therefore, to commercial wastewater. If additional inflow of such wastewater is likely in the future, this should also be considered in the plant design.

Innovative designs can reduce the cost of the facility. Examples include:

- baffled reactors and anaerobic filters located under pavements, carparks, playgrounds or streets
- positioning the facility to minimise land use and length of sewerage systems
- application of reliable standards to minimise sewer diameters.



Picture 6_14:
Detailed engineering design

6.4.4 Economic planning

Economic planning includes calculating the overall project costs and developing a strategy for covering these costs.

The costs to be considered are for:

- land
- materials
- labour
- supervision – including optional planning
- operation – electricity, water, CSC service provision etc.
- maintenance – desludging and sludge treatment.

Where CSCs and DEWATS are to be constructed, the question of land ownership must be resolved. In order to purchase real estate, negotiations must be held with the owner – a site is either private or municipal property. If the owner is not willing to sell the land, perhaps a long-term lease of 15 to 20 years can be obtained. Alternatively, a usufruct may be granted for publicly owned sites. Agreements on the land ownership or renting scheme should be finalised before more activities start.

The quantity and volume of the necessary building materials can be calculated using the detailed engineering design. The total costs for construction depend on context:

- If construction is carried out by employees, local wages and material costs apply;[28] in-kind community contributions should also be included in the calculation.
- If there is a bidding process, estimated prices should be used – their final prices factored in after the tender is accepted.
- If operation and maintenance is supplied by a service provider, a call for tenders can be launched
- If operation is carried out by the community itself, local labour and running costs should be added in

28 A local government makes a financial contribution to a project, market prices may not apply; many authorities have price codes, which must be used instead

Cost coverage can be achieved with possible financial contributions from:

- residents
- public authorities and
- international donors

The fee structure for a CSC should be based on the completed assessment of the users' willingness to pay. If full-cost coverage cannot be expected, further implementation should be postponed.

6.4.5 Agreement on implementation and landholding

In some locations it was helpful to formulize the overall process by signing a Memorandum of Understanding (MoU). The document, signed by a legal representative of the community and relevant municipal bodies, became a central part of the CBS-development plan. It is very important to ensure that the whole community supports the project, as individual disagreements can jeopardise the entire process at a later stage. A community meeting should be held, therefore, to discuss the results of the project planning and to smoothe out any remaining concerns before commencing with implementation.

The main points of the MoU included in the development plan are:

- geographical and topographical maps
- detailed engineering design
- budget plan – including the schedule for disbursements and detailed statements about the contributions from different stakeholders
- implementation schedule
- operation and maintenance plans
- ownership
- responsibilities during implementation (planning & construction)
- responsibilities after implementation (operation & maintenance)

6.5 Implementation phase

6.5.1 Task planning

The implementation schedule is developed from the tasks and respective workloads defined during the economic-planning phase. Tasks are grouped into categories and listed on a spreadsheet.

No.	Tasks	Volume	
A. Wastewater-treatment system tasks			
1	Prepare building site & levelling	1.00	–
2	Provide office space and storage	1.00	–
3	Documentation	3.00	–
1	Levelling	64.43	m^3
2	Prepare sand-bed	12.00	m^3
3	Refill earth	16.11	m^3
1	Lay brickwork	77.93	m^3
2	Prepare concrete reinforcement	40.64	m^3
3	Plaster	124.27	m^2
4	Prepare working subgrade	6.00	m^3
5	Lay brickwork	560.32	m^2
1	Pipes PVC Ø 6“	2.00	Bt
2	Pipes PVC Ø 4“	61.00	Bt
3	Pipes PVC Ø 2“	2.00	Bt
4	T-piece	80.00	Bh
5	Manhole cover	13.00	Bh
B. Sewerage system tasks			
1	Exavation	305.00	m^3
2	Refill earth	101.67	m^3
3	Prepare sand-bed	75.50	m^3
1	Prepare concrete reinforcement	0.94	m^3
2	Watertight plastering of manholes	0.00	m^2
3	Open road surface	398.00	m^2
1	Pipes PVC Ø 6“	152.50	Bt
2	Pipes PVC Ø 4“	48.00	Bt
3	Mount prefabricated manhole	35.00	Bt

Table 8: Example of an implementation schedule

The amount of work predicted in the detailed engineering design and economic planning is entered into the table. Task sequences are determined and the required time for each task is estimated.

Time planning requires CBS project experience and knowledge of local conditions (e.g. weather conditions during different seasons, cultural and religious events and holidays, financial allocation patterns of governments and the community). The schedule must be prepared, therefore, by experienced local staff, or by experts in cooperation with people who have local knowledge.

The average time required to construct a community sanitation centre in Indonesia ranges between 70 and 90 days. For household-based sanitation systems, including simplified sewerage and off-site treatment, 90 to 110 days can be estimated.

Picture 6_15: Task planning should be carried out by experts

6.5.2 Quality management

The requirements for a sound planning and implementation are too ofen underestimated. Quality management during construction, therfore, is an essential element of the successful long-term operation of CSC/DEWATS. The systems must be constructed as high-quality products. Poor construction quality and minor faults, such as bad plastering or the use of poor-quality bricks, may result in the failure of the entire system. Construction should only be carried out, therefore, by contractors and companies who can be guaranteed to use of high-quality materials and labour. Different quality-control models have proven successful in the construction of anaerobic wastewater-treatment systems:

- In Nepal, only licensed contractors are entitled to construct biogas plants. If the qualitiy of work is unacceptable, the constructor risks losing his/her licence and will be excluded from the programme.
- In Indonesia, a network of NGOs promoting DEWATS and CBS has developed an internal certification system to assure the proper application of new developed quality standards. Only certified products and personnel may participate in the implementation of such facilities. High standards are ensured by certified:
  - planners
  - foremen
  - site engineers
  - supervisors
  - design engineers and
  - senior design engineers[29]

Picture 6_16: Ensuring good-quality workmanship is essential for a successful CBS programme

Efficient quality management goes hand in hand with capacity building; on-site training measures should be an integral part of any programme. Especially in programs aimed at large-scale implementation, quality-control and standardisation procedures must become common elements to ensure effective and efficient use of the resources.

29 Requirements include: 1) education: minimum level or experience, 2) training – completion of a training programme 3) examination – training combined with tests, 4) repeated examination – every second year, 5) practical experience – adequate involvement in the different steps of DEWATS implementation (further information can be found in the annex).

6.5.3 Construction

The construction process and its main components are summarised in the table below:

	Community sanitation centre	Simplified sewerage, incl. off-site treatment	Shared septic tank
Sanitation module	**Preparation work** • Survey and prepare site • Arrange materials procurement • Arrange tools and machinery • Arrange work force **Earth work** • Excavate • Levell • Fill earth and compact • Fill sand and compact **Concrete work** • Cast concrete slab • Carry out brick work • Plastering **Carpentry & roofing** • Topping-out the truss • Roofing **Assembly Work** • Mount piping • Sanitary equipment • Water & electricity supply • Other interior fittings	**Preparation work** • Survey and prepare site • Arrange materials procurement • Arrange tools and machinery • Arrange work force **Install sanitary equipment at appropriate location** **Concrete work** • Cast concrete slab • Carry out brickwork • Plastering **Install and connect piping to collection system** **Assembly work** • Mount piping • Sanitary equipment • Water supply • Other interior fittings	**Preparation work** • Survey and prepare site • Arrange materials procurement • Arrange tools and machinery • Arrange workforce **Install sanitary equipment at appropriate place** **Concrete work** • Cast concrete slab • Carry out brickwork • Plastering **Install and connect piping to collection system** **Assembly work** • Mount piping • Sanitary equipment • Water supply • Other interior fittings
Collection module	Install and connect piping to treatment system (sub-soil below CSC)	**Preparation work** • Survey and prepare location line • Arrange materials procurement • Arrange tools and machinery • Arrange workforce **Earth work** • Excavate • Levell • Fill earth and compact • Fill sand and compact **Install inspection chamber** • Cast concrete slab • Carry out brickwork • Plastering **Lay sewer pipes** **Fill construction ditches and compact**	**Preparation work** • Survey and prepare location line • Arrange material procurement • Arrange tools and machinery • Arrange work force **Earth work** • Excavate • Levell • Fill earth and compact • Fill sand and compact **Install inspection chamber** • Cast concrete slab • Carry out brickwork • Plastering **Lay sewer pipes** **Fill construction ditches and compact**

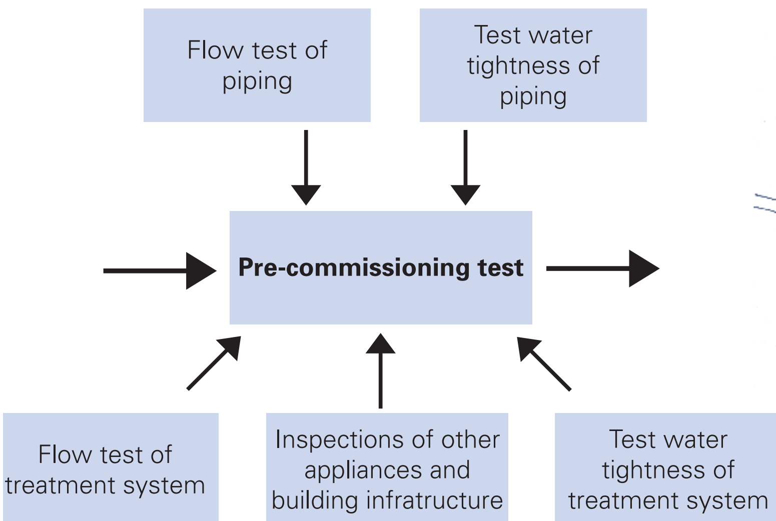
Table 9:
Detailed description of construction process

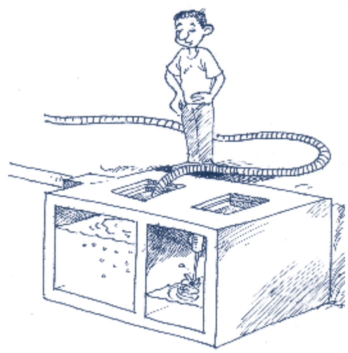
	Community sanitation centre	Simplified sewerage, incl. off-site treatment	Shared septic tank
Treatment module	Preparation work • Survey and prepare site • Arrange materials procurement • Arrange tools and machinery • Arrange workforce Earth Work • Excavate • Levell • Fill earth and compact • Fill sand and compact Concrete work • Cast concrete slab • Carry out brickwork • Plastering Assembly work • Mount piping • Fill filters	Preparation work • Survey and prepare site • Arrange materials procurement • Arrange tools and machinery • Arrange workforce Earth Work • Excavate • Levell • Fill earth and compact • Fill sand and compact Concrete work • Cast concrete slab • Carry out brickwork • Plastering Assembly work • Mount piping • Fill filters	Preparation work • Survey and prepare site • Arrange materials procurement • Arrange tools and machinery • Arrange workforce Earth work • Excavate • Levell • Fill earth and compact • Fill sand and compact Concrete work • Cast concrete slab • Carry out brickwork • Plastering Assembly work • Mount piping • Fill filters
Discharge module	Preparation work • Survey and prepare location • Arrange materials procurement • Arrange tools and machinery • Arrange workforce Earth work • Excavate • Levell • Fill earth and compact • Fill sand and compact Install inspection chamber • Cast concrete slab • Carry out brickwork • Plastering Lay Sewer Pipes Fill construction ditches and compact	Preparation work • Survey and prepare location • Arrange materials procurement • Arrange tools and machinery • Arrange workforce Earth work • Excavate • Levell • Fill earth and compact • Fill sand and compact Install inspection chamber • Cast concrete slab • Carry out brickwork • Plastering Lay Sewer Pipes Fill construction ditches and compact	Preparation work • Survey and prepare location • Arrange materials procurement • Arrange tools and machinery • Arrange workforce Earth work • Excavate • Levell • Fill earth and compact • Fill sand and compact Install inspection chamber • Cast concrete slab • Carry out brickwork • Plastering Lay Sewer Pipes Fill construction ditches and compact

Table 9ff:

6.5.4 Pre-commissioning test

In order to ensure good construction quality, the system is tested by technical experts from the LA upon completion. All technical modules are evaluated with regard to engineering design, quality of workmanship and functional efficiency. System flow and the water-tightness of the piping and treatment system are scrutinised closely. Technical drawings and checklists serve as tools for the pre-commissioning test.





Picture 6_17: Pre-commissioning test

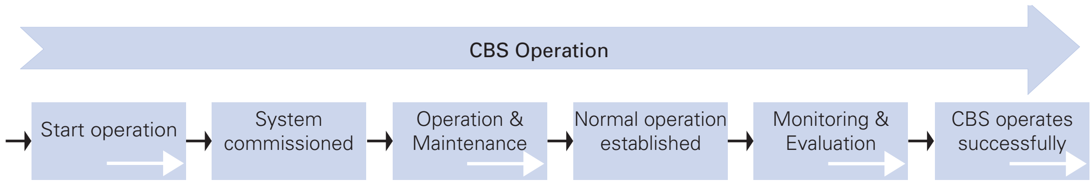
Picture 6_18: Only fully functioning systems are accepted

6.5.5 Parallel training measures

- Environmental-health training is encouraged in all CBS projects. The training is target at everyone in the community – members and individuals involved in operational activities. The aim of the training is to explain the importance of sanitation facilities for personal and environmental health and to provide an understanding of the broader context of sanitation. The main subjects include personal hygiene, handling human excreta and rubbish, disease transmission and background information on particular diseases, such as diarrhoea, typhoid and dengue fever. Training is based on the guidelines of the PHAST (Participatory Hygiene and Sanitation Transformation) Initiative, jointly developed by WHO and UNDP/World Bank Water and Sanitation Programme.

- Function and application training is a basic training module for all users of the new sanitation infrastructure. The aim is to impart basic knowledge about the system works. Correct use of the system is explained along with information about what may harm functional efficiency. The training comprises a theory and a practice module. The practical training should be carried out on site after construction is finished.
- Operation and maintenance training is only given to people directly involved in the operation and maintenance activities. Basic information on wastewater treatment and the function of the system is provided as well as an overview of all routine tasks for operation and maintenance. The various operational faults and necessary maintenance steps are also discussed.

6.6 Operation phase

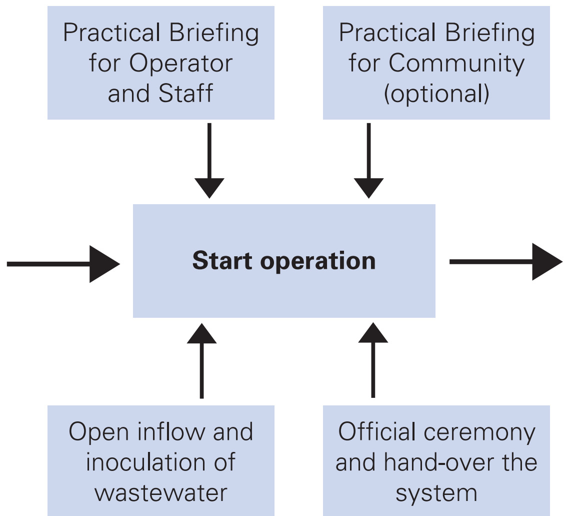


Picture 6_19: Flow chart: operation phase

6.6.1 Start operation

Operation is usually initiated by technical experts from the LA in coallboration with the intended operators. For fast start-up, baffled reactors and biogas plants should be inoculated with digested sludge from existing anaerobic wastewater-treatment units, such as septic tanks. After starting the system, operators are briefed on operation and maintenance.

The system formally starts operation at a hand-over ceremony with the community and/or the operating agency. Particularly in poor areas, such events should be perceived as a positive gesture towards the development of the area.

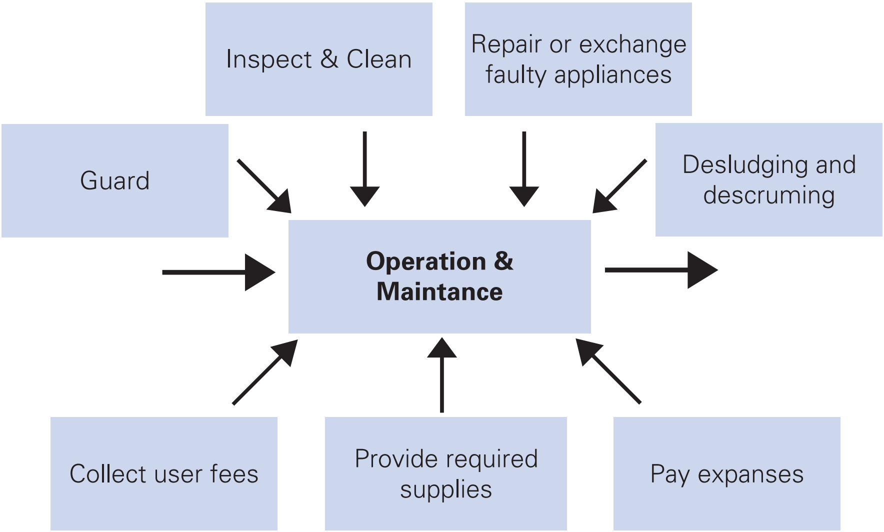


Picture 6_20:
Start operation

Picture 6_21:
The opening ceremony is welcomed by the residents

6.6.2 Operation & maintenance

Operation and maintenance should be backed by a detailed-up contracts. Depending on the approach, the community operating body or an external operator, such as an NGO, a public entity or private company, can be responsible for the operation and maintenance. The leading agency should sign formal agreements with the relevant parties, clearly defining the terms of reference. A contract with a service provider could, for example, include the following terms:



Picture 6_22: Possible operation and maintenance tasks

- Community sanitation centres have to be operated and guarded from 5:00 until 22:00
- The entrance areas (terraces) must always be maintained properly (must be cleaned at least twice a day)
- Toilets, shower cells, laundry places and the rest of the plot must be inspected and cleaned daily
- Faulty appliances, such as light bulbs and leaking pipes, must be replaced.
- The seal of the bio-digester has to be checked for gas tightness and water has to be re-filled on a weekly basis
- Inspection chambers have to be checked and cleaned every week

- The water tank has to be cleaned and cobwebs have to be removed every month.
- Every six month, the system must be inspected by professional technical staff, who will sample wastewater, analyse of effluent water and de-scum treatment modules.
- The treatment system must be desludged every two years
- User fees must be collected
- All operation and maintenance activities must be documented

Picture 6_23: Operation & maintenance manual

inspection shaft to the bottom of the treatment tank before the vacuum pump is switched on. During desludging only matured "black" sludge should be removed. Establishing sludge-management service is one of the main challenges for public bodies. Without such services wastewater-treatment systems stop functioning. Without adequate regulations and law enforcement many housholds and public and private entities practise uncontrolled discharge of their sludge, leading to great environmental risks and health hazards.

Even if the desludging infrastructure has been established, must be monitored. Positive results achieved with a model, have been users pay the serviceprovider with a "chip", for which the service provider gets paid through the municipality after delivering the sludge to the treatment facility; users puchase the "chips" local government. This system prevents corruption and the service provider dumping the waste.

Picture 6_24: Monitoring is required to ensure that service providers handle, treat and dispose sludge in accordance with regulations

6.6.3 Use of biogas

The use of DEWATS-generated biogas is highly recommended because it:

- makes use of a renewable-energy source
- reduces greenhouse gases, which would otherwise escape from the treatment process

The efficient and sustainable use of the biogas requires:

- sufficient production of biogas
- maintenance of the biogas equipment
- clear definition of who is entitled to is use the biogas

Within CBS projects, biogas is normally used for application, such as cooking, water heating or lighting. Experience shows that tensions can arise within the community if it is unclear who is entitled to use the biogas – leading to a waste of the resource in some projects. Positive results were achieved where the service providers or individuals responsible for the operation and maintenance of the overall system received the benefit. Since they handle the CBS on a daily basis, these individuals already have a deeper understanding of biogas production and can be trained to incorporate the maintenance of the biogas equipment into their other maintenance duties.

Maintenance duties for biogas appliances include:

- cleaning biogas burners and pipes to prevent clogging with water vapours
- replaceing of biogas lamp mantles regulary

The project leaders should make sure the decision about biogas use on early is made in the project. Once the stakeholders agree, the future users can be trained to maintains of the biogas equipment, while it is being installed.

Picture 6_25: Only fully functioning systems are accepted

Picture 6_26: Biogas equipment has to be well-maintained

6.6.4 Monitoring and evaluation

The performance of the wastewater-treatment system should be checked every 6 to 12 months. The inlet and outlet quality should be analysed to verify if legal standards are being met. Results can be compared to the target performance (planning phase) to optimise the design of future plants.

Daily records should be kept by the operator and operating body so that the service can be evaluated. Records should include data on the daily number of users, specific problems and the executed operation and maintenance activities carried out. Where systems are badly operated, or the number of users decreases with time; the LA should investigate the reasons and take appropriate action. This might include replacing the service providers or revising the operation and maintenance scheme.

Picture 6_27
Monitoring of the operation and maintenance scheme contributes to sound operation of CBS

DEWATS can be constructed and operated successfully almost anywhere because they rely on natural wastewater-treatment processes, without special equipment, chemicals, or energy supply. This chapter explains the treatment processes and how they apply to different DEWATS components, in order to guide the reader in appropriate technical selection and design.

The chapter is sub-divided into the following sections:
- Basics of wastewater treatment
- Parameters for wastewater-treatment design
- DEWATS – technical components
- Dimensioning of DEWATS

7.1 Basics of wastewater treatment

7.1.1 Definitions: pollution & treatment

Pollution is the undesirable state of the environment being contaminated with substances, which disturb the natural balance of nature and can lead to health consequences for flora, fauna and humans.

Although domestic wastewater is mainly organic, the high concentration of the substances has a polluting effect on open-water bodies, groundwater or soil, due to the oxygen-draining chemical and bio-chemical reactions that result.

Phosphorus and nitrogen are essential nutrients for plant growth. Their introduction to water bodies can generate great algae populations, which limit the amount of sunlight that can shine into the water, thereby leading to excessive oxygen consumption within the water body until other aquatic life-forms can no longer survive. Furthermore, nitrogen is poisonous to fish in the form of ammonia gases and may also become poisonous to other life-forms, including humans, in the form of nitrite.

Most heavy metals are toxic or carcinogenic. They harm the aquatic life of the receiving water and affect humans through the food chain. Pathogens, including helminth eggs, protozoal cysts, bacteria and viruses, are responsible for innumerable cases of disease and death in the world.

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Treatment consists of a wide range of procedures that relieve the negative effect of the pollutants, by removing or changing harmful substances into a harmless or less-harmful state. DEWATS treatment depends on natural bio-chemical and physical processes including:

- degradation of organic matter until the point at which chemical or biological reactions stop (stabilisation)
- physical separation and removal of solids from liquids
- removal of toxic or otherwise-dangerous substances (for example, heavy metals or phosphorous), which are likely to distort sustainable biological cycles, even after stabilisation of the organic matter

7.1.2 Biological treatment

Stabilisation occurs through degradation of organic substances via chemical processes, which are biologically steered (bio-chemical processes). The processes are the result of bacterial metabolism, in which complex and high-energy molecules are transformed into simpler, low-energy molecules. Metabolism is the transformation from feed to faeces to gain energy for life, in this case for the life of bacteria, which store and release the gained energy in the form of ATP (adenosine triphosphate). A few chemical reactions happen without the help of bacteria. In the main, wastewater treatment is the degradation of organic compounds, and subsequent oxidisation of carbon (C) to carbon dioxide (CO_2), nitrogen (N) to nitrate (NO_3), phosphorus (P) to phosphate (PO_4) and sulphur (S) to sulphate (SO_4). Hydrogen (H) is also oxidised to water (H_2O). In anaerobic processes, some of the sulphur is formed into hydrogen sulphide (H_2S), producing the typical "rotten-egg smell". The largest amount of oxygen (O) is required for burning carbon ("wet combustion").

The process of oxidation happens aerobically with free dissolved oxygen (DO) present in water, or anaerobically without oxygen from outside the degrading molecules. Anoxic oxidation takes place when oxygen is taken from other organic substances.

Facultative processes include aerobic, anoxic and anaerobic conditions, which prevail at the same time at various parts of the same vessel or at the same place after each other. In anoxic respiration and anaerobic fermentation, as there is no oxygen available, all oxygen must come from substances within the substrate. Anaerobic treatment is never as complete as aerobic treatment because there is not enough oxygen available within the substrate itself. The chemical reactions under aerobic, anoxic and anaerobic conditions are illustrated by the decomposition of glucose:

Decomposition via aerobic respiration:
$C_6H_{12}O_6 + 6O_2 = CO_2 + 6H_2O$

Decomposition via anoxic respiration:
$C_6H_{12}O_6 + 4NO_3 = 6CO_2+6H_2O+2N_2$

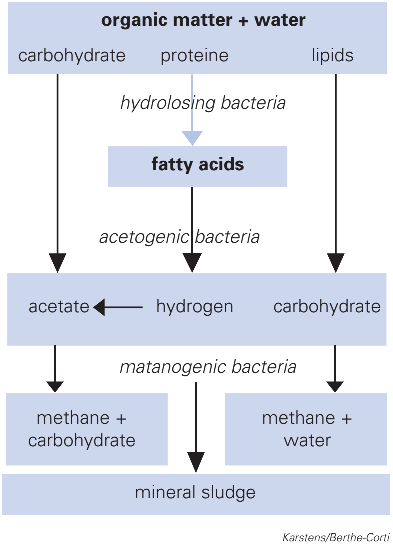
Decomposition via anaerobic fermentation:
$C_6H_{12}O_6 = 3CH_4+3CO_2$

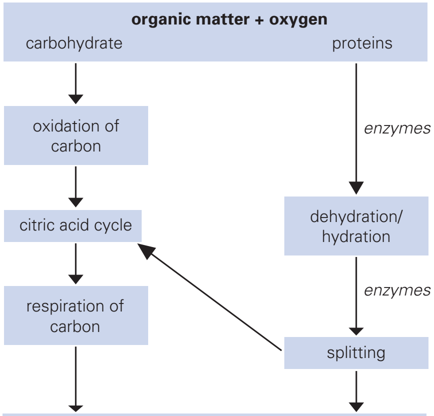
Bacteria need nutrients to grow. Any living cell consists of C, H, O, N, P and S. Consequently, any biological degradation demands N, P and S beside C, H and O. Trace elements are also needed to form specific enzymes. Enzymes are specialised molecules, which act as a kind of "key" to "open-up" complex molecules for further degradation.

Carbohydrates and fats (lipids) are composed of C, O and H and cannot be fermented in pure form (Lipids are "ester" of alcohol and fatty acids; an ester is a composition that occurs when water separates off). Proteins are composed of several amino acids. Each amino acid is composed of a COOH-group and a NH_3-group plus P, S, Mg or other necessary trace elements. Thus, proteins contain all the necessary elements and, consequently, can be fermented alone. A favourable proportion between C, N, P and S (varying around a range of 50:4:1:1) is a pre-condition for optimum treatment.

7.1.3 Aerobic – anaerobic

Aerobic decomposition takes place when dissolved oxygen is present in water. Composting is also an aerobic process. Anoxic digestion occurs when dissolved oxygen is not available, but bacteria get oxygen for energy "combustion" by breaking it away from other, mostly organic substances present in wastewater, predominantly from nitric oxides. Anaerobic digestion breaks up molecules composed of oxygen and carbon to ferment them to carbohydrates.





The aerobic process is very diverse; the above diagram has been almost unacceptably simplified.
However, it shows that carbohydrates and proteins undergo different steps of decomposition. It also shows the importance of enzymes for breaking up proteins.

Picture 7_1:
The anaerobic process in principle

Picture 7_2:
The aerobic process in principle

The aerobic process happens much faster than anaerobic digestion and therefore dominates when free oxygen is available. The high speed at which decomposition takes place is caused by the shorter reproduction cycles of aerobic bacteria as compared to anaerobic bacteria. Anaerobic bacteria leave some of the energy unused, which is released in the form of biogas. Aerobic bacteria use a larger portion of the pollution load for production of their own bacterial mass compared to anaerobic bacteria, which is why aerobic processes produce twice the amount of sludge compared with anaerobic ones. For the same reason, anaerobic sludge is less slimy than aerobic sludge and is easier to drain and dry.

Aerobic treatment is highly efficient when there is enough oxygen available. However, compact aerobic treatment tanks need external oxygen, which must artificially be supplied by blowing or via surface agitation. Such technical input consumes technical energy.

The anaerobic treatment process is slower. It demands a higher digestion temperature quasi to make up for the unused nutrient energy. Since the treatment process is supported by higher ambient temperatures, it is well suitable role for DEWATS in tropical and subtropical countries. Ambient temperatures between 15° and 40°C are sufficient. Anaerobic digestion (fermentation) releases biogas (CH_4 + CO_2), which can be used as a fuel.

7.1.4 Physical treatment processes

Wastewater treatment relies on the separation of solids, both before and after stabilisation. Even dissolved particles are decomposed into the three main fractions: water, gases and solids, of which the solids have to be removed. The choice of method for solid removal depends on the size and specific weight of the suspended solids.

Screening

Screening of larger solids is the foremost step in conventional treatment plants. In DEWATS, screening is not advisable because screens require cleaning at very short intervals, i.e. daily or weekly, which demands a safe storage and treatment space in the immediate vicinity for the removed screenings. A blocked screen is an obstacle that plugs the entrance of the plant. DEWATS should allow for the full amount of wastewater to pass through the plant without obstructions. If this fails, it may happen – and, in fact, happens quite often – that the operator "organises“ a trouble-free by-pass, which pollutes the environment, as if the treatment plant did not exist. For this reason it is recommended to avoid screens and, instead, provide sufficient additional space to accommodate larger solids within the first sedimentation chamber.

Sedimentation

Separation of solids happens primarily by gravity, predominantly through sedimentation. Coarse and heavy particles settle within a few minutes or hours, while smaller and lighter particles may need days and weeks to finally sink to the bottom. Small particles may cling together, forming larger flocs that also sink quickly. Such flocculation happens when there is enough time and little to no turbulence; stirring hinders quick sedimentation. Sedimentation is slow in highly viscose substrate.

Sedimentation of sand and other discrete particles works best in vessels with a relatively large surface. These vessels may be shallow, since depths of more than 50 cm have no influence on the sedimentation process in the case of discrete particles.

grain size in mm	1	0.5	0.2	0.1	0.05	0.01	0.005
quartz sand	502	258	82	24	6.1	0.3	0.06
coal	152	76	26	7.6	1.5	0.08	0.015
SS in domestic wastewater	120	60	15	3	0.75	0.03	0.008

Table 10: Settling speed of coarse particles. Suspended sludge particles have settling properties different from coarse particles. Source: K.+K. Imhoff, pg. 126

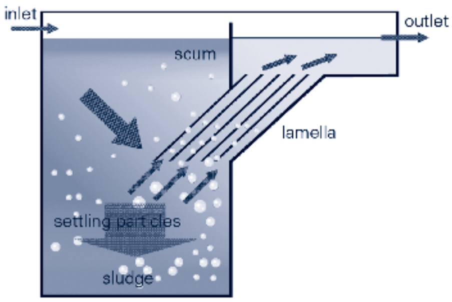
This is different for finer coagulant particles, where sedimentation increases with basin depth. This is because settling particles meet suspended particles to form flocs which continue to grow larger and larger on their way to the bottom. A slow and non-turbulent flow - still and undisturbed water - supports "natural" coagulation for sedimentation.

Settled particles accumulate at the bottom. In the case of wastewater, any sediment also contains organic substances, which begin to decompose. This decomposition, which occurs in any sludge sedimentation basin and to a lesser extent in grit chambers, results in the formation of carbon dioxide, methane and other gases. These gases are trapped in sludge particles that float to the top when the numbers of gas molecules increase. This process not only causes turbulence; it also ruins the success of the sedimentation that has taken place. The Imhoff tank through its baffles prevents such gas-driven particles from "coming back" to spoil the effluent. The UASB process deliberately utilises this balance of sedimentation (= down stream velocity) and up-flow of sludge particles (= upstream velocity).

After decomposition and the release of gases, the stabilised (mineralised) sludge settles permanently at the bottom, where it accumulates and occupies tank volume. It must be removed at regular intervals. Since many pathogens, especially helminths, also settle well, sedimentation plays an important role in hygienic safety of domestic or husbandry wastewater treatment.

Floatation

Floatation is the predominant method for fat, grease and oil removal. In high-tech, conventional wastewater treatment the process is also used to remove small particles by injecting fine air bubbles to the bottom of the tank.

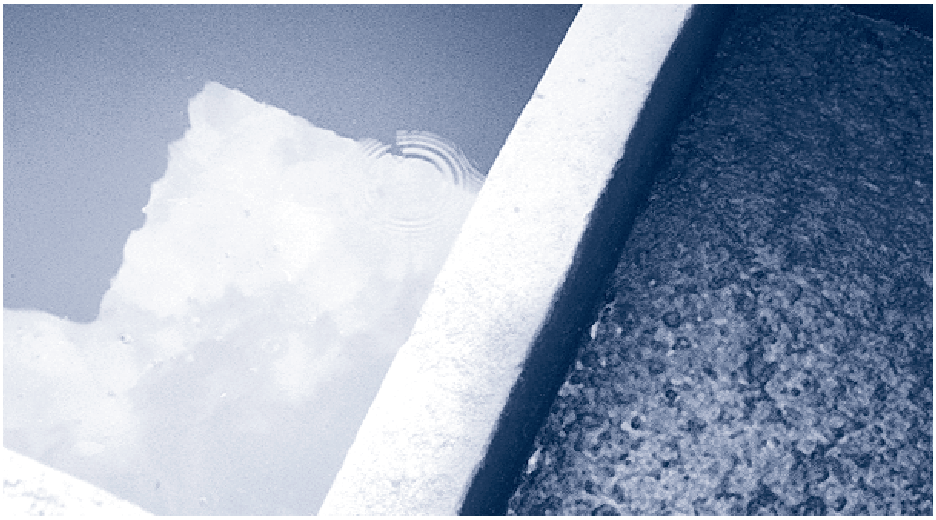


Picture 7_4: Lamella solids separator, lamella may be made of plastic sheets, concrete slabs or PVC pipes

Most fatty matter can be checked by simple observation tests, similar to settleable solids. If fats, which are detected by laboratory analysis, are not separated by floatation, they present themselves as colloids, which can only be removed after pre-treatment (after acidification, e.g.).

Unwanted floatation occurs in septic tanks and other anaerobic systems, where floating layers of scum may form. Accumulating scum can be removed manually, or can be left purposely to "seal" the surface of anaerobic ponds, preventing bad odour.

Floatation and sedimentation, can be improved by installing slanted lamella sheets or several layers of slanting pipes. These surfaces artificially increase the separation of solids from liquids by facilitating floc and gas accumulation.



Picture 7_3: Partition wall retaining scum, inlet is at the right side, water flows below the partition wall into the compartment at the left side

Filtration

Filtration is necessary for the removal of suspended solids, which do not "self-flocculate", settle or float within a reasonable time. Most filters have a double function: While forming a physical obstacle for smaller solid particles, they also provide a fixed surface on which treatment bacteria can grow. Both bacterial growth and accumulated solids can lead to clogging of the filter. Physical filters retain solids which accumulate, unless they are removed. Coarse filters, where physical filtration occurs primarily with the help of bacteria growth, can be cleaned by flushing. Bacteria and suspended solids are hereby flushed away simultaneously, as for example is typically done with trickling filters. Upstream filters may be back-flushed. The filter material of sand and finer gravel filters must be removed, cleaned and replaced after several years of use.

Needless to say, filters with smaller grain size provide more efficient treatment. On the other hand, effective filtration requires the retention of many solids and therefore leads to faster clogging. The permeability and durability of filters is always reciprocal to its treatment efficiency. Filter material of round and almost equal grain size is more efficient and renders longer service than filters of mixed grain size.

Aerobic filters produce more sludge than anaerobic filters and consequently block faster. However, they also have a self-cleaning effect when given sufficient resting time, as the aerobic bacteria in the sludge practise a kind of "cannibalism" (autolysis) when nutrient supply stops.

Sludge accumulation

Sedimentation and filtration lead to sludge accumulation at the bottom of vessels. With time, the sludge compacts; consequently older sludge occupies less volume than fresh sludge. Sludge removal intervals are therefore important design criteria (see chapter 14). Adequate handling and treatment of the sludge are required.

7.1.5 Elimination of Pollutants

Elimination of Nitrogen

Nitrogen removal occurs in two steps: nitrification followed by denitrification, which results in pure nitrogen diffusing into the atmosphere.

Nitrification is oxidation. Nitrate is the most stable form of nitrogen and its presence indicates complete oxidation. Denitrification is reduction, or the separation of that very oxygen from the oxidised nitrogen. The pure gaseous nitrogen that remains is insoluble in water, and therefore evaporates easily. Nitrogen escaping from the denitrification process may cause floating foam or scum, similar to the effect seen from the gas release by settled anaerobic sludge. Since nitrogen is the major compound of air it is ecologically harmless.

During nitrification NH_3 (ammonia) is oxidised by a special group of bacteria - called nitrobacter - to NO_3 (nitrate). Since nitrobacter grow slowly, a higher sludge age and thereby longer retention time is needed for oxidation of nitrogen (= nitrification) than is required for oxidation of carbon.

noxious substance group	1 NSU is eqal to
oxidisable matter	50 kg COD
phosphorous	3 kg P
nitrogen	25 kg N
organic fixed halogenes	2 kg AOX
mercury	20 g Hg
cadmium	100 g Cd
chromium	500 g Cr
nickel	500 g Ni
lead	500 g Pb
copper	1000 g Cu
dilution factor for fish toxicity	3000 m³

Table 11:
Rating of noxious substances according to German law. Mercury is the most dangerous substance on the list. Source: Imhoff, 1990

Denitrification occurs faster than denitrification, as several groups of bacteria are able to utilise nitrate oxygen under anoxic conditions (absence of free oxygen). Incomplete denitrification may lead to formation of the poisonous nitrite (NO_2), instead of nitrate (NO_3).

This happens because the time left for the bacteria to consume all the oxygen is not enough or because there is not enough organic material left to absorb the NO_3-oxygen. Some none-DEWATS treatment processes recycle nutritious sludge to prevent such nutrient deficiency. A certain amount of nitrate in the effluent could also be a source of oxygen for the receiving water. In DEWATS, nitrate removal usually does not receive special attention, in that additional technical measures are not taken.

Elimination of Phosphorus

Bacteria cannot transform phosphorous into a form in which it loses its fertiliser quality permanently. Phosphorous compounds remain potential phosphate suppliers. This implies that no appropriate biological process, either aerobic or anaerobic can remove phosphorus from wastewater. Phosphorus removal from water "normally" takes place by removal of bacteria mass (active sludge) or by removal of phosphate fixing solids via sedimentation or flocculation. Iron chloride, aluminium sulphate or lime fix phosphates, a fact that can be utilised by selecting suitable soils in ground filters. However, removal of phosphorus in root zone filters has not proven to be as efficient and sustainable as expected and propagated by the pioneers of these systems.

Elimination of Toxic Substances

Since heavy metals settle easily, their removal is not difficult. Heavy metal contaminated sludge must be handled accordingly and disposed of safely, at proper landfill sites. Other toxic substances may be soluble and thus difficult to remove. There are numerous methods to eliminate or transform toxins into non-toxic matters, which cannot be described here. More specialised literature may be consulted.

High salt content inhibits biological treatment and is very difficult to remove. In the case of saline water used for domestic or industrial purposes, for example, the water remains saline even after treatment. It should therefore not be used for irrigation and should not be allowed to enter the groundwater table or receiving rivers that carry too little water. Costly ion-exchangers may have to be used to break-up the stable mineralised molecules of salts.

Removal of Pathogens

Even after treatment, wastewater should be handled carefully. Underground filtration and large pond systems are relatively efficient in pathogen removal, but not necessarily to an extent so that wastewater can be called safe for bathing – let alone drinking. However, reuse for irrigation is safe under certain conditions .

Helminth eggs and protozoa accumulate in sediment sludge and are thereby largely retained inside the treatment system, where they stay alive for several weeks. Most bacteria and viruses caught in the sludge die after shorter periods. Pathogens, which are not caught in the sludge and remain suspended in the effluent are hardly affected. This is especially true in high rate reactors, like filters or activated sludge tanks. These bacteria and viruses exit the plant fully alive, although the risk of virus infection from wastewater has proven to be low.

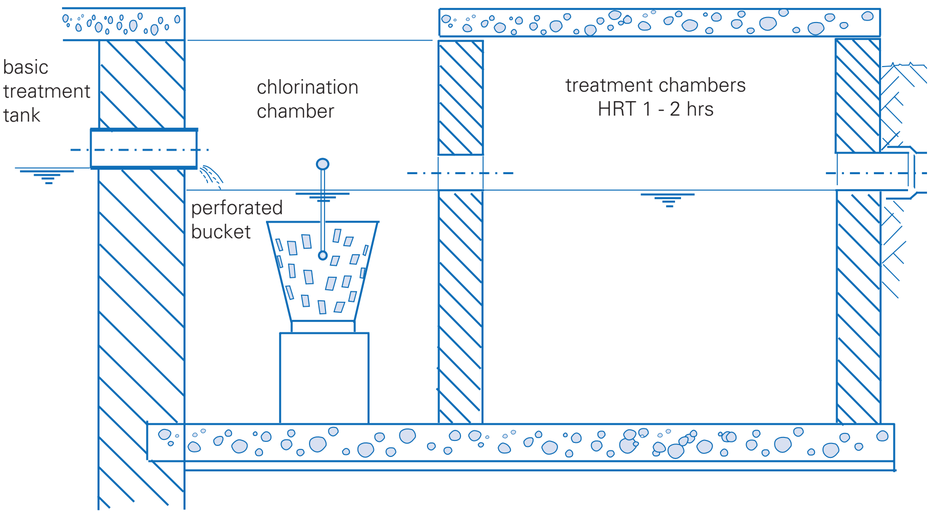
type of infection, type of wastewater	country	dose of chlorine g/m³	contact time h	total rest chloride mg/l
intestinal pathogens	China		> 1,0	5
tubercular pathogens	China		> 1,5	7
raw wastewater	Germany	10 - 30	0,25	traces
post treatment	India	3		
post treatment	Germany	2	0,25	traces
odour control	Germany	4	0,25	traces

Table 12:
Comparing the use of chlorine for different requirements at various places. Different sources

Exposure to UV rays has a substantial hygienic effect. The highest rate of pathogen removal can be expected from shallow ponds with long retention times, e.g. 3 ponds in a row with HRT of 8 - 10 days each. Constructed wetlands with their multifunctional bacterial life in the root zones can also be very effective. However, it is the handling after treatment, which ensures hygienic standards.

Using chlorination to kill pathogens in wastewater is only advisable for hospitals in the case of epidemics and similar circumstances. It may also be applied in slaughterhouse treatment plants, which are only a short distance from a domestic water source. Permanent chlorination is never advisable, as it has adverse effects on the environment: Water is made unsuitable for aquatic life, as chlorine itself has a high chemical oxygen demand (COD).

Bleaching powder (chlorinated lime) containing approximately 25% Cl is most commonly used as a source of chlorine. Granular HTH (high test hyperchlorite) containing 60 to 70% Cl is available on the market under different brand names. Since chlorination should not be a permanent practice, a chamber for batch supply, followed by a contact tank of 0,5 - 1 h HRT will be sufficient).



Picture 7_5: Post treatment chlorination carried out in a batch chamber for small scale applications. The bucket is filled with bleaching powder, which is washed out automatically. This plant is acceptable for emergency disinfection of effluent from rural hospitals only because controlled dosing is not possible.

7.1.6 Ecology and self-purification in nature

An Understanding of the self-purification ability of the natural environment helps in designing DEWATS intelligently. On the one hand, only harmless wastewater should be discharged; on the other hand, nature may be incorporated into the design for the completion of the treatment processes.

Surface water

The biological self-purification effect of surface waters depends on the climate, weather and on the relative pollution load in the water. The presence of free oxygen is a precondition for the self-purification process. The higher the temperature, the higher the rate at which the degrading bacteria, which are responsible for purification, multiply. At the same time, the intake of oxygen via surface and oxygen solubility drops with increasing temperature. Rain and wind increase the oxygen-intake capacity. Consequently, acceptable pollution loads or wastewater volumes must be dimensioned according to the season with the least favourable conditions (for example, winter or summer in temperate zones, dry season in the tropics).

It is difficult to reanimate water once the self-purification effect has stopped as from then on, it enters the anaerobic stage.Extreme seasonal changes make it difficult to maintain the self-purification effect of water throughout the year. However, nature has a way of helping itself, as in the case of lakes and rivers that dry out in long dry seasons when the remains of organic matter compost and are fully mineralised before the next rains come.

Minerals retain their fertilising quality even after drying. This is why it is better to bring sludge at the bottom of dried lakes, canals or rivers to the fields before it is washed away into the receiving water by the first heavy rains and its rich nutrient value is lost. However, the content of toxic matter in sludge should be observed. The most important source of oxygen for natural water in an ecosystem is oxygen from the air, which dissolves in water via surface contact. Floating fat, grease or oil films restrict oxygen transmission from the air and require additional oxygen decomposite.

The nutrients cantatred in wastewater increase algae growth. In a healthy ecosystem, algae produce oxygen during the day and consume part of this oxygen at night.

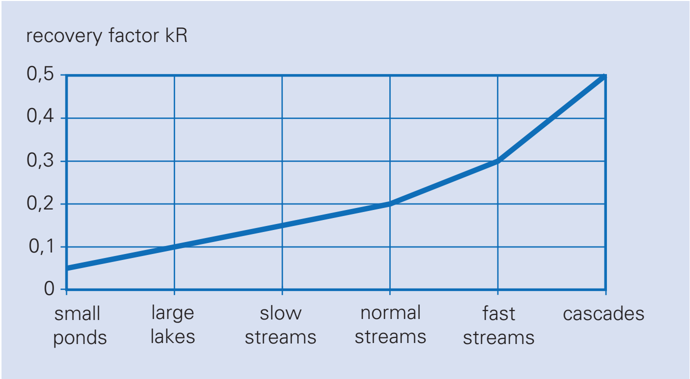
If the algae population were to become unduly dense, sunlight would not be able to penetrate the dark-green water. Are a result, the algae would consume oxygen during the day as well – and the supply of free oxygen that is needed for aquatic life would decrease.

Picture 7_6: DEWATS at a Hotel in Cochin, India; large-size ponds are used for post-treatment

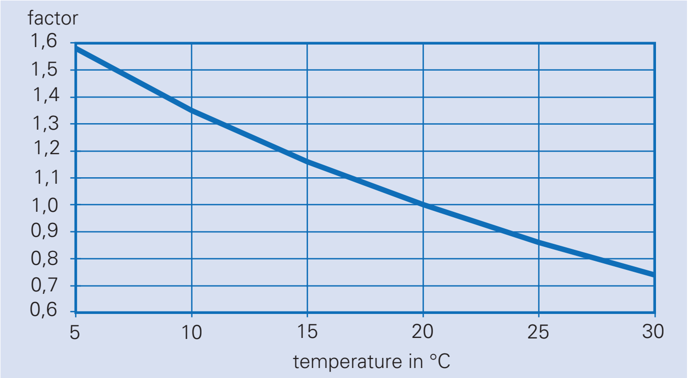
The degree of pollution, in particular, and the content of dissolved oxygen (DO), can be gauged by the variety of plant and animal species found in the water. The colour of the water of rivers and lakes is yet another indicator of the quality of the water. Green or green-brownish water is indicative of high nutrient supply due to algae; a reddish-rosy colour indicates facultative algae and a severe lack of free oxygen; black is often indicative of complete anaerobic conditions of suspended matter.

Nitrogen in the form of nitrate (NO_3) is the main polluting nutrient. In the form of ammonia (NH_3) it is also a major, oxygen-consuming toxic substance, therfore nitrogen should be kept away from living waters; notwithstanding that nitrate may also function as an oxygen donor in certain instances.

The next most-important polluting nutrient is phosphorus, which is mainly present in the form of hydrogen phosphate (H_2PO_4). Since phosphorus is often the limiting factor for the utilisation of other nutrients, its presence in surface waters is dangerous, as even in small doses it may lead to an oversupply of nutrients. Nitrogen that is normally plentiful needs 10% of phosphorus to be of use to plants. That means phosphorus activates ten times as much nitrogen and, therefore may be considered the most polluting element to any receiving water. At the same time, it is this property that makes wastewater rich in phosphate an excellent fertiliser when used for irrigation in agriculture.



Picture 7_7:
Oxygen recovery after pollution of natural waters. Turbulence increases oxygen intake and reduces time for recovery



Picture 7_8:
Oxygen intake of natural waters reduces with rising temperatures

Phosphorus accumulates in closed ecosystems, for example in lakes. Unlike nitrogen that is eliminated, phosphorus remains potentially active in the residue of dead plants, which have previously consumed it. For example, phosphate fixed by iron salts can be set free under anaerobic conditions in the bottom sludge, where it is available for new plant growth. It is for this reason that continuous supply of phosphate into lakes is prohibited. While this may seem less dangerous for flowing waters, it must be realised that all rivers end somewhere, at which point phosphorus will accumulate.

While chloride may be used for disinfecting effluents from hospitals and slaughterhouses, it must be remembered that chloride also disinfects the receiving waters, thereby reducing their self-purification ability.

It is self-evident that toxic substances should not enter any living water. Most toxic substances become harmless in the short term, particularly if they are sufficiently diluted. However, most toxic materials are taken in by plants and living creatures and, in the long run, accumulate in the aquatic lifecycle. Fish from such waters become unsuitable for human consumption and heavy metals accumulate in the bottom sludge of receiving waters, where they remain as a time-bomb for the future.

Groundwater

Groundwater was once rainwater. It is the most important source of water for domestic use, irrigation and other purposes. The supply of groundwater is not infinite. To be sustainable, it must be recharged. Rather than simply draining used water into rivers that carry it to the sea, it would be better to purify this water and use it to recharge the groundwater.

Organic pollution of groundwater happens in cases where wastewater enters underground water-streams directly. A crack-free, 3 m-thick soil layer above groundwater is sufficient to prevent organic pollution. Pollution by mineralised matters is possible, however, as salts like nitrate and phosphate are soluble in water and cannot be eliminated by physical filtration when passing through soil or sand layers. Some pathogens may also reach the groundwater despite soil filtration. Viruses can be dangerous, due to their infectious potential, irrespective of their absolute number.

Nitrate is easily soluble in water. So it is easily washed out from soil into groundwater, especially in sandy soil during periods when vegetation is low (for example, winter in cold climates). Groundwater, therefore, will always contain a certain amount of nitrate (mostly above 10 mg/l).

Nitrate (NO_3) in itself is rather harmless. For example, in the European Union, drinkingwater may legally contain nitrate up to 25 mg/l. It is, however, latently dangerous, as nitrate is capable of changing to nitrite (NO_2) under certain biological or chemical circumstances. This process can even occur inside human blood, where nitrite attaches itself to haemoglobin, reducing the capacity of the haemoglobin to "transport" oxygen – leading to suffocation. Nitrite poses the greatest risk to babies, who have a greater tendency to form nitrite. For this reason, water used for the production of baby food must always contain less than 10 mg/l NO_3.

Soil

Pollution can render soils useless for agricultural production. For example, the pH may drop as a result of incomplete anaerobic digestion of organic matter. This is particularly common in clay or loamy soils, where oxygen supply is insufficient due to the physical closure of pores in the soil by suspended solids from wastewater irrigation. Furthermore, soil pollution poses a threat because of washout effects that harm surface- and groundwater alike. Mineral salts in small doses do not pose a problem for wastewater treatment. Using saline wastewater for irrigation over a long period of time, however, may cause complete and irreversible salination of the topsoil. Clay and loamy soils with slow downward percolation are themost affected, as water evaporates from the top layers, leaving the salt behind.

On the other hand, sandy soils may benefit from irrigation with wastewater even when the organic load is high, provided that oxygen can be supplied to deeper soil layers. Well-treated wastewater, containing mineralised nitrogen, phosphorus and other trace elements, can improve soil conditions and is environmentally safe, as long as the application of nutrients is balanced with its in-take by plants. Applying of treated wastewater throughout the year, regardless of demand, may have adverse effects. Nutrients wil be washed out into water bodies at times when plant growth is negligible, with the result that nutrients are not available to the plants when needed.

8 Treatment in DEWATS

DEWATS make use of the natural biological- and physical-treatment processes discussed above to reduce and remove pollutants from wastewater. External energy supply, dosing of chemicals and movable parts are avoided to minimise both possible flaws in operation and maintenance.

As the various natural-treatment processes require different boundary conditions to function efficiently, DEWATS are comprised of a series of treatment units, each providing an ideal environment for the removal of certain groups of pollutants. Stability of the treatment system is ensured, as each treatment step only removes the "easy part" of the pollution load, sending the leftovers to the following step.

Picture 8_1: Several steps are required for full treatment

Sedimentation	→	Anaerobic digestion	→	Anaerobic decomposition	→	Post-sedimentation
removal of easily settleable solids		removal of easily degradeable organic solids		removal of more difficult degradable solids		removal of digested solids and active bacteria mass

The term "phase separation" has a double meaning. On the one hand it is used for the separation of gas, liquid and solids in anaerobic reactors; on the other hand it is used to describe the technical separation of different stages of the treatment process, either in different locations or in sequences of time intervals. The latter kind of phase separation becomes necessary when suitable nutrients cannot be provided simultaneously to bacteria, which have differing growth rates and prefer different feed. Some bacteria multiply slowly while others grow rapidly. As not all the enzymes required for degradation are found in all substances, the bacteria take time to produce adequate amounts of the missing enzymes. As disscussed previously, enzymes act as the "key which opens the lock of the food box for bacteria".

Substrates, for which enzymes are immediately available, can easily be degraded; substrates, which first require the bacterial production of specific enzymes, are degraded much more slowly. In an environment which hosts substances that are both easy and difficult to degrade, the bacterial population responsible for easy degradation tends to predominate.

To protect the "weaker" (slower) bacteria, it is advisable to artificially separate bacterial populations in phases by providing each with its own favourable environment. The characteristics of the wastewater and the desired treatment results must be identified, before the dimensions of the treatment vessels for the different phases can be designed.

In the case of DEWATS, it is often easiest to provide longer retention times, so that the "slow" bacteria find their food after the "fast" bacteria have satisfied their demand. This process is easier to manage and, in the case of smaller plants, it is cheaper to design certain units this way. In other units, like the baffled septic tank, the efficiency of the treatment in subsequent chambers justifies its higher cost; processes, which require feeding the plant with sequencing flow rates involving steering and control, are thereby avoided.

Phase separation becomes unavoidable if different phases require either anaerobic or aerobic conditions. In the case of nitrogen removal, longer retention times alone do not provide adequate treatment conditions because the nitrifying phase needs an aerobic environment, while denitrification requires an anoxic environment. Anoxic means that nitrate (NO_3) oxygen is available, but free oxygen is not. Anaerobic means that neither free oxygen nor nitrate-oxygen is available. Nevertheless, the aerobic phase can only lead to nitrification if the retention time is long enough for the "slow" nitrifying bacterium to act, as compared to the "quick" carbon oxidisers.

Pre-composting of plant residues before anaerobic digestion is another example of simple phase separation, where lignin is decomposed aerobically before anaerobic bacteria can reach the inner parts of the plant material (lignin cannot be digested anaerobically because of its "closed" molecular structure).

8.1 Parameters for Wastewater-Treatment Design

Treatment must remove or reduce pollutants within the wastewater sufficiently to prevent harm to the environment and humans. Before deciding is made, which kind of treatment is necessary and which dimensions each unit requires, planners and designers must identify the following:

- quality and quantity of the raw wastewater
- local conditions and their influence on treatment processes
- standards to be fulfilled in final use or discharge

Laboratory analysis is used to determine the quantity and quality of the pollution load, the feasibility of treatment, the environmental impact under local conditions – and whether a particular wastewater is suitable for biogas production. Some parameters can even be seen and understood by experienced observation.

As the quality of wastewater changes according to the time of day and from season to season, the analysis of data is never absolute. It is far more important that the designer understands the significance of each parameter and its "normal" range than to know the exact figures. Ordinarily, an accuracy of ±10% is more than sufficient.

This chapter gives a concise overview, introducing:

- control parameters, essential for characterising wastewater and
- dimensioning parameters, utilised in DEWATS design

Detailed analysing techniques may be found in books for laboratory work or comprehensive handbooks on wastewater, like Metcalf and Eddy's *"Wastewater Engineering"*.

8.1.1 Control parameters

Volume

The volume or the flow rate of wastewater determines the required size of the building structure – upon which the feasibility or suitability of the treatment technology is decided. It is essential not to underestimate the peak flow.

Surprisingly, the determination of flow is often rather complicated, due to the fact that flow rates change throughout the day or with the season, and that volumes have to be measured in "full size“. It is not possible to take a sample which stands for the whole. In the case of DEWATS, it is often easier and more practical to measure or enquire about the water consumption rather than try to measure the wastewater production. The flow of wastewater is not directly equal to water consumption, since not all the water that is consumed ends up in the drain (for example, water for gardening), and because wastewater might be a mix of used water and stormwater. If possible, stormwater should be segregated from the treatment system, especially if it is likely to carry substantial amounts of silt or rubbish. Rainwater drains should never be connected to the treatment plant, however, ponds and ground filters will be exposed to rain. The volume of water in itself is normally not a problem as hydraulic loading rates are not likely to be doubled and a certain flushing effect might even be advantageous. Soil clogging (silting) could become a problem, however, if stormwater reaches the filter after having eroding the surrounding area.

For high-rate reactors, like anaerobic filters, baffled septic tanks and UASB, the flow rate per hour could be a crucial design parameter. If exact flow data is not available, the hours of the day, which account for most of the flow, should be determined and used. Hydraulic retention-time calculations should take into account of the fluctuation influence.

The flow rate is calculated by collecting and measuring volumes per time period. Possible measurement techniques include monitoring the rise in level of a canal that is closed for a period of time, or the number of buckets filled during a given period. Another good indicator of the actual flow rate is the time it takes, during initial filling for the first tank of a treatment plant to overflow.

In larger plants the flow rates are normally measured with control flumes (for example, the Parshall flume) where a rise in level before a slotted weir indicates the flow.

Solids

Total solids (TS) or dry matter (DM) include all matter, which is not water. Organic total solids (OTS) or volatile solids (VS) are the organic fraction of the total solids. TS is found by drying the sample. The inorganic fraction is found by burning the dry matter and measuring what remains as ash. TS minus ash is OTS or VS. Solids may be measured in mg/l or as a percentage of the total volume.

The parameter "suspended solids" (SS) describes how much of organic or inorganic matter is not dissolved in water. Suspended solids include settleable solids and non-settleable suspended solids. Settleable solids sink to the bottom within a short time. They can be measured with a standardised procedure in an Imhoff-cone, in relation to a defined settling time of 30 minutes, one hour, two hours or one day. Measurement of settleable solids is the easiest method of wastewater analysis because solids are directly visible in any transparent vessel. For collecting initial on-site information, any transparent vessel will do (for example, water bottles, which should be destroyed for hygienic safety after use).

Table 13: Domestic wastewater derives from various sources. Composition of wastewater depends largely on standard of living and domestic culture. Source: Metcalf&Eddy, 1996

range source	min g/cap*d	max g/cap*d
feces (solids, 23%)	32	68
ground food wastes	32	82
wash waters	59	100
toilet (incl. paper)	14	27
urine (solids, 3.7%)	41	68

Non-settleable suspended solids consist of particles which are too small to sink to the bottom within a reasonable (technical) time. SS is determined by sample filtration. Suspended solids are an important parameter because they cause turbidity in the water and may cause physical clogging of pipes, filters, valves and pumps.

Colloids are very fine suspended solids (< 0.1 m) which pass normal filtration paper, but are not fully dissolved in water (dissolved solids are single molecules that are spread out among the water molecules). A high percentage of fatty colloids can create large problems in fine-sand filters.

In domestic wastewater, the BOD derives to approximately one third (33%) from settleable solids, to half (50%) from dissolved solids, while one sixth (17%) of the BOD derives from non-settleable SS (see Table 18).

Fat, grease and oil

Fat and grease are organic matter that is biodegradable. However, since they float on water and have a sticky consistency their physical properties are a problem in the treatment process and in nature. It is best to separate fat and grease before biological treatment.

The amount of fat that remains in treated domestic wastewater is normally small. A fat content of approximately 15 to 60 mg/l is allowed in the effluent of slaughterhouses or meat-processing plants for discharge into surface waters. Mineral grease and mineral oils – like petrol or diesel – although they may also be treated biologically, should be kept away from the treatment system. Their elimination is not within the scope of DEWATS.

Turbidity, colour and odour

Most wastewaters are turbid because the solids suspended in them break the light. So highly turbid fluid indicates a high percentage of suspended solids. Metcalf and Eddy define the relationship between turbidity and suspended solids in the following equation:

SS [mg/l] = 2,35 × turbidity (NTU), or

turbidity (NTU) = SS [mg/l] / 2,35[30]

30 Metcalf&Eddy, 1996; page 257

NTU is the standardised degree of turbidity. Its value can be determined with the help of a turbiditimeter or by standardised methods, which measure the depth of sight of a black cross on a white plate. Turbidity may prevent algae in surface waters from producing oxygen during daytime, as would otherwise be the case.

The colour is not only indicative of the source of wastewater, but also of the state of degradation. Fresh domestic wastewater is grey, while aerobically degraded water tends to be yellow, and water after anaerobic digestion turns blackish. Turbid, black water may be easily settleable because suspended solids sink to the bottom after digestion when given enough undisturbed time to form flocs. A brownish colour indicates incomplete aerobic or facultative fermentation.

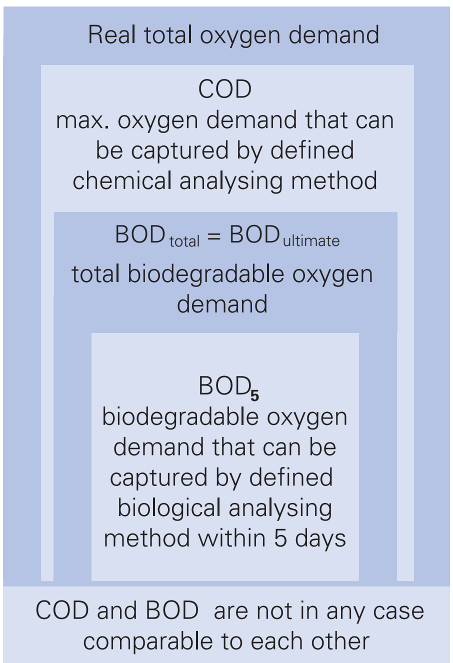
Wastewater that does not smell probably contains enough free oxygen to restrict anaerobic digestion – or the organic matter has long since been degraded. A foul smell ("like rotten eggs") comes from H_2S (hydrogen sulphur), which is produced during anaerobic digestion, especially at a low pH. A foul smell, therefore indicates that free oxygen is not available and that anaerobic digestion is still underway. Vice versa, whenever there is substantial anaerobic digestion there will always be a foul smell.

Fresh wastewaters from various sources also have characteristic smells. Experience is the best basis for making conclusions: making wastewater will smell like dairy wastewater, distillery wastewater will smell like distillery wastewater, etc. "Smelling the performance“ of treatment plants is an important skill. An alert wastewater engineer should „collect“ different odours and their causes, to build up a repertoire of experience for the future occasions.

COD and BOD

COD (Chemical Oxygen Demand) is the most common parameter for measuring organic pollution. It describes how much oxygen is required to oxidise all organic and inorganic matter found in the water. The BOD (Biochemical Oxygen Demand) is always a fraction of the COD. It describes how much oxygen is required for the oxidisation of matter, which can be oxidised biologically with the help of bacteria. It is equal to the organic fraction of the COD. Under standardised laboratory conditions at 20°C, it takes about 20 days to activate the total carbonaceous BOD (=BODultimate, BODtotal). In order to save time, BOD-analysis determines the biological oxygen demand after five days. The result is called which BOD_5, in practice, is commonly referred to simply as BOD. The BOD_5 is a certain fraction (approximately 50 to 70%) of the absolute BOD. This fraction is different for each wastewater. The ratio of BODtotal to BOD_5 is wider with difficult degradable wastewater and, thus, it is also wider with partly treated wastewater.

COD and BOD are the results of standardised laboratory-analysis methods. They do not fully reflect the bio-chemical truth, but are reliable indicators for practical use.



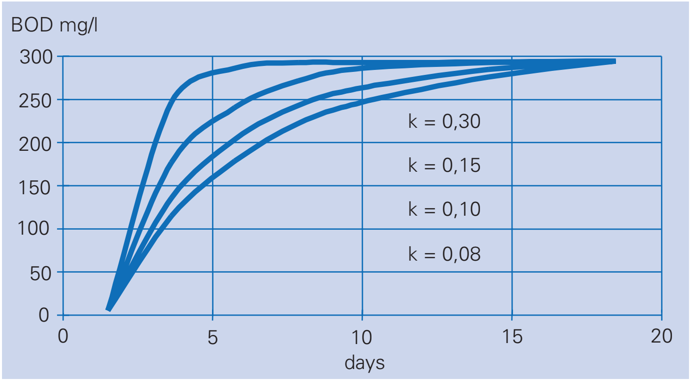
Picture 8_2: Definition of oxygen demand. The BOD_5 is a part of the total BOD; the total BOD may be understood as part of the COD; and the COD is part of the absolute real oxygen demand. The total BOD may be equal to the COD; the COD may be equal to the real oxygen demand

Biological oxygen demand describes the portion of the wastewater which can be digested easily, for example, anaerobically. The COD/BOD_{total} vaguely indicates the relation of total oxidisable matter to organic matter, which is degraded first by the most common bacteria. For example, if a substrate is toxic to bacteria, the BOD is zero; the COD nonetheless may be high, as would be the case with chlorinated water. In general, if the COD is much higher than the BOD (>3 times) one should check the wastewater for toxic or non-biodegradable substances.

In practice, the quickest way to determine toxic substances is to have a look at the shopping list of the institution which produces the wastewater.
The kinds of detergent bought by a hospital may be more revealing than a wastewater sample taken at random. It is important to know that the COD in a laboratory test shows the oxygen donated by the test-substance, which is normally $K_2Cr_2O_7$ (potassium dichromate). The tested substrate is heated to mobilise the chemical reaction (combustion). Occasionally, KMnO4 (potassium permanganate) is used for quick on-site tests. The COD_{cr} is approximately twice as much as the COD_{Mn}; however, the two values do not have a fixed relation, which is valid for all wastewaters.

Easily degradable wastewater has a COD/BOD relation of about 2. The COD/BOD ratio widens after biological, especially anaerobic treatment because biological degradation has already taken place. COD and BOD concentrations are measured in mg/l or in g/m³. Absolute values are measured in g or kg. A weak wastewater from domestic sources, for example, may have a COD below 500 mg/l while a strong industrial wastewater may have up to 80,000 mg/l BOD.

Picture 8_3: BOD-removal rates are expressed by rate constants (k) which depend on wastewater properties, temperature and treatment-plant characteristics. The curve shows the BOD-removal rates at 20°C. The value after 5 days is known as BOD_5



When too much BOD or COD is discharged into surface waters, the oxygen present in that water is consumed for the decomposition of the pollutants and, thus, is no longer available for aquatic life. Effluent standards for discharge into receiving waters may tolerate 30 to 70 mg/l BOD and 100 to 200 mg/l COD.

Wastewater analysis sometimes states the total organic carbon (TOC). This indicates a how much of the COD can be attributed to carbon only. In designing DEWATS, knowledge of BOD or COD is sufficient; TOC is of no practical concern.

toxic metal	concentration mg/l
Cr	28-200
Ni	50-200
Cu	5-100
Zn	3-100
Cd	70
Pb	8-30
Na	5000-14000
K	2500-5000
Ca	2500-7000
Mg	1000-1500

Table 14: Concentration of toxic substances which inhibit anaerobic digestion. Source: Mudrak/Kunst, 1991

Nitrogen (N)

The types of nitrogen compounds found in wastewater are good indicators for which treatment steps are currently happening or have happened. Nitrogen is a major component of proteins (albumen). A high percentage of albuminoid nitrogen indicates fresh wastewater. During decomposition, when large protein molecules are broken up into smaller molecules, nitrogen is found in the form of free ammonia (NH_3). However, ammonia dissolves in water and forms ammonium (NH_4+) at low pH levels. At a pH level above 7, NH_4+ transforms to NH_3. There is always a mass balance between NH_3 and NH_4. NH_3 evaporates into the atmosphere, which leads to unwanted nitrogen losses, if the treated wastewater is intended for irrigation. Ammonium further oxidises to nitrite (NO_2-) and finally to nitrate (NO_3-).

From the chemical symbol, it is evident that ammonia (or ammonium) will consume oxygen to form nitrate, the most stable end-product. The albuminoid and the ammonia nitrogen together form the organic nitrogen, also called Kjeldahl-N (N_{kjel}). The total nitrogen (N_{total}) is composed of N_{kjel} (not oxidised N) and nitrate-N (oxidised N).

Pure nitrogen (N_2) is formed when oxygen is separated from NO_3 to oxidise organic matter. Since pure nitrogen hardly dissolves in water, it evaporates immediately into the atmosphere, an attribute used to remove nitrogen from wastewater in the process of denitrification. Nitrification (under aerobic conditions) followed by denitrification (under anoxic conditions) is the usual process of removing nitrogen from wastewater.

For optimum bacterial growth, untreated wastewater should have a BOD/N relation of 15 to 30. Nitrogen is normally not monitored in the effluent of smaller plants. Discharge standards for the effluent of larger plants permit 10 to 20 mg/l of N_{kjel}-N.

Phosphorus (P)

Phosphorus (P) is an important parameter for planning the treatment of unknown wastewater, especially in relation to BOD, nitrogen or sulphur. Bacterial growth demands approximate ratios of BOD/P and N/P of 100 and 5, respectively. Insufficient amounts of phosphorus lead to lower bacterial activity and, therefore poorer removal of COD (BOD).

High phosphorus content in the effluent leads to water pollution by algae growth. However, since phosphorus removal in DEWATS is hardly worth mentioning, it is the least important parameter to the designing engineer. Discharge standards for larger plants allow P in the range of 1 to 5 mg/l.

Temperature

Temperature is an important parameter, as warmer surroundings promote bacterial growth. Anaerobic digestion requires minimal temperatures of 10°C; temperatures between 18 and 25°C are good, 25 to 35°C are ideal. Anaerobic processes are more sensitive to low temperatures than aerobic ones because the bacteria achieve lower energy gains for themselves, through the production of biogas, as an oxidiseable, energy-rich end-product. The ambient temperatures in tropical and subtropical zones are ideal for anaerobic treatment; the process is very suitable for DEWATS.

Higher temperatures are also favourable for the growth of aerobic bacteria, but disadvantageous for oxygen transfer (Picture 7_8). A warmer environment reduces the capability of water to absorb oxygen from the air. This is the reason why ponds may become anaerobic at the height of summer.

pH-value

The pH-value indicates whether a liquid is acidic or alkaline. The scientific definition of the pH is rather complicated and of no interest to practical engineering (it indicates the H-ion concentration). Pure water has a pH of 7, which is considered to be neutral. An effluent of neutral pH indicates optimal treatment performance. Wastewater with a pH below 4 to 5 (acidic) and above 9 (alkaline) is difficult to treat; mixing tanks may be required to buffer or balance the pH level. In the case of a high pH, ammonia-N dominates, whereas ammonium-N is prevalent at low pH-values.

Volatile fatty acids

Volatile fatty acids (VFA) are used as a parameter to check the state of the digestion process. A high amount of VFA always coincides with a low pH. Fatty acids are produced at an early stage of digestion. The presence of too many fatty acids indicates that the second stage of digestion, which breaks up the fatty acids, is not keeping pace with acidification. This indicates that the retention time is either too short or that the organic pollution load on the treatment system is too high. Values of VFA inside the digester in the range of BODinflow values indicate a stable anaerobic process.

Dissolved oxygen

Dissolved oxygen (DO) describes how much oxygen is freely available in water. The parameter indicates the potential for aerobic treatment and is usually applied to assess the quality of surface waters. DO is vital to aquatic life: most species of fish require a minimum of 4 to 5 mg/l DO for survival and breeding.

Pathogens

The World Health Organisation (WHO) distinguishes between high-risk transmission of intestinal parasites (helminths eggs), and lower-risk transmission of diseases caused by pathogenic bacteria. Indicators for these risks are the number of helminths eggs and the number of faecal coliforms, respectively. For uncontrolled irrigation less than 10,000 e-coli per litre and less than 1 helminth egg is permitted by the WHO standard. E-coli bacteria are not pathogenic, but are a good indicator of faecal bacteria. Regardless of the number of ova, bacteria or viruses, wastewater is generally unsafe to humans.

Organism	Disease/symptoms
	Virus (lowest frequency of infection)
polio virus	poliomyelitis
coxsackie virus	meningitis, pneumonia, hepatitis, fever, common colds, etc.
echo virus	meningitis, paralysis, encephalitis, fever, common colds, diarrhoea, etc.
hepatitis A virus	infectious hepatitis
rota virus	acute gastroenteritis with severe diarrhoea
norwalk agents	epidemic gastroenteritis with severe diarrhoea
reo virus	respiratory infections, gastroenteritis
	Bacteria (lower frequency of infection)
salmonella spp.	salmonellosis (food poisoning), typhoid fever
shigella spp.	bacillary dysentry
yersinia spp.	acute gastroenteritis, diarrhoea, abdominal pain
vibro cholerae	cholera
campylobacter jejuni	gastroenteritis
escherichia coli	gastroenteritis
	Helminth worms (high frequency of infection)
ascari lumbrocoides	digestive disturbance, abdominal pain, vomiting, restlessness
ascaris suum	coughing, chest pain, fever
trichuris trichiura	abdominal pain, diarrhea, anaemia, weight loss
toxocara canis	fever, abdominal discomfort, muscle aches, neurological symptoms
taenia saginata	nervousness, insomnia, anorexia, abdominal pain, digestive distrubance
taenia solium	nervousness, insomnia, anorexia, abdominal pain, digestive distrubance
necator americanus	hookworm disease
hymenolepsis nana	taeniasis
	Protozoa (mixed frequency of infection)
cryptosporidium	gastroenteritis
entmoeba histolytica	acute enteritis
giardia lamblia	giardiasis, diarrhoea, abdominal cramps, weight loss
balantidium coli	diarrhea, dysentery
toxoplasma gondii	toxoplasmosis

Table 15: Wastewater transmitted diseases and their symptoms

Exact pathogen counts are of limited importance for DEWATS design. Bacterial or helminth counts are important when wastewater is discharged into surface waters, which are used for bathing, washing, or irrigation.

Domestic wastewater and effluents from meat-processing plants and slaughter-houses, which carry the risk of transmitting blood-borne diseases, like hepatitis, are particularly dangerous. The handling and discharge of such effluents may demand special precautions.

8.1.2 Dimensioning parameters

Hydraulic load

The hydraulic load is the most common parameter for calculating reactor volumes. It describes the volume of wastewater to be applied per volume of reactor, or per surface area of filter, within a given time. The usual dimension for the hydraulic load of reactors is $m^3/(m^3 \times d)$, meaning that 1 m^3 of wastewater is applied per 1 m^3 of reactor volume per day. The reciprocal value denotes the hydraulic retention time (HRT). For example, 1 m^3 wastewater on 3 m^3 of reactor volume results in a hydraulic load of 0.33 $m^3/(m^3 \times d)$, which is equal to a hydraulic retention time of three days (3 m^3 volume/1 m^3 of water per day).

The hydraulic retention time (HRT) gives a relation of volumes. It does not, for example, distinguish between sludge and liquid. The hydraulic retention time of a septic tank states nothing about the fraction of wastewater, which stays inside the tank for longer, nor does it say anything about the time that the bottom sludge has for digestion. In the case of vessels filled with filter media, the actual hydraulic retention time depends on the pore space of the media. For example, certain gravel consists of 60% stones and 40% pore space between the stones. A retention time of 24 hours per gross reactor volume is thereby reduced to 40%, which gives a net HRT of only 9.6 hours.

For groundfilters and ponds, the hydraulic loading rates may be expressed in $m^3/(ha \times d)$, $m^3/(m^2 \times d)$ or $l/(m^2 \times d)$. Alternatively, the value may be stated in cm or m height of water cover on a horizontal surface. For example, 150 litres of water applied per square of meter land is equal to 0.15 m^3/m^2, which in turn is equal to 0.15 m or 15 cm hydraulic load.

Hydraulic loading rates are also responsible for the flow speed (velocity) inside the reactor. This is of particular interest in the case of up-flow reactors, like UASB or baffled septic tanks, where the up-flow velocity of liquid must be lower than the settling velocity of sludge particles. In such cases, the daily flow must be divided by the hours of actual flow (peak-hour flow rate). For calculating the velocity in an up-flow reactor, the wastewater flow per hour is divided by the surface area of the respective chamber (V = Q/A; velocity of flow equals flow divided by area). When splitting one large reactor into several chambers in series, it must be considered that the up-flow velocity in each chamber is greater than in the original large reactor. This is due to the fact that the flow rate per hour remains the same, while the area through which the flow passes is reduced to individual chambers. The necessity to keep velocity low, therefore, can lead to relatively large digester volumes, especially in baffled septic tanks.

Organic load

For strong wastewater, the organic loading rate – and not the hydraulic loading rate – becomes the determining parameter. In the case of tanks and deep anaerobic ponds, the calculation is done in grams or kilograms of BOD_5 (or COD) per m^3 digester volume per day. For shallow aerobic ponds, organic loading is related to the surface area using the dimensions grams or kilograms of BOD_5 (or COD) per m^2 or ha per day.

Table 16: Organic-loading rates and removal efficiencies of various treatment systems. Sources: mixed

typical values	aerobic pond	maturation pond	water hyacinth pond	anaerobic pond	anaerobic filter	baffled reactor
BOD_5 kg/m³*d	0.11	0.01	0.07	0.3-1.2	4.00	6.00
BOD_5 removal	85%	70%	85%	70%	85%	85%
temperature optimum	20°C	20°C	20°C	30°C	30°C	30°C

The permitted organic loading rate is influenced by the time needed by the various kinds of bacteria for their specific metabolism under the given conditions (often expressed as rate constant k). This, in turn is, influenced by the kind of reactor, the reactor temperature and the kind of wastewater. Easy-to-degrade substrate can be fed at higher loading rates because the bacteria involved multiply fast and consume organic matter quickly. For difficult-to -degrade substrate, some of the bacteria species require longer.

Excessive loading rates can lead to "poisoning" and the process collapsing because end-products from one step of fermentation cannot be consumed by the ensuing group of bacteria. In anaerobic digestion, for example, overloading leads to acidification of the substrate, preventing final methanisation.

At very low loading rates, almost no sludge is produced because the bacteria "eat each other" for want of feed (autolysis). Consequently, incoming wastewater is not met by sufficient bacteria populations for decomposition. Although low organic loading rates do not destabilise the process, they do reduce overall treatment efficiency.

Sludge volume

The volume of sludge is an important parameter for designing sedimentation tanks and digesters. This is because the accumulating sludge occupies tank volume that must be added to the required reactor volume. The amount of biological sludge production is directly related to the amount of BOD removed which, however, depends on the decomposition process. Aerobic digestion produces more sludge than anaerobic fermentation. In addition to the biological sludge, primary sludge consists partly of settled solids, which are already mineralised.

	mineral dry matter		organic dry matter		total dry matter		BOD_5	
	g/cap.*d	g/m³	g/cap*d	g/m³	g/cap.*d	g/m³	g/cap.*d	g/m³
settleable solids	20	100	30	150	50	250	20	100
suspended solids	5	25	10	50	15	75	10	50
dissolved solids	75	375	50	250	125	625	30	150
Total	100	500	90	450	190	950	60	300

Table 17:
Average distribution of solids of domestic wastewater in Germany.
Source: Imhoff, 1990

Large, conventional sewage-treatment works remove sludge continuously and often under water – producing a very liquid sludge with a low, total solid content of between 1 and 5%. In DEWATS, the sludge remains inside the tank for at least one year, where it decomposes under anaerobic conditions and undergoes further volume reduction, as it compacts under its own weight with time.

Although the literature varies widely, it can be assumed that approximately 0.005 litres of sludge per gram BODremoved accumulate in the primary treatment step of DEWATS, including a certain percentage of mineral settleable particles. There is sludge accumulation in secondary treatment as not all digested organic matter accumulates as settleable sludge, and mineral particles have already been removed. A sludge value of 0.0075 litres per gram BODremoved can be assumed for oxidation ponds, taking additional sludge from algae into account. The above figures are estimates for "modern" domestic wastewater as described in Table 18. True sludge production is influenced by the wastewater's settling properties, ratio of organic and mineral matter content and physical boundary conditions. Further details on sludge handling and treatment can be found in Chapter 11.

Table 17:
Properties of primary sludge
Source: Metcalf&Eddy, 1996

Properties of sludge from primary sedimentation		
specific grafity of solids kg/l	specific grafity of sludge kg/l	dry solids g/m³
1,4	1,02	150,6

Additional benefits of wastewater treatment

The possible additional benefits of wastewater treatment should be considered at an early stage of planning so that can be incorporated into the design.

Where and how the treated effluent is disposed or used affects the form of treatment that is required. While the removal of nutrients may be beneficial for the discharge into open water bodies or groundwater, it is counterproductive for reuse in agricultural irrigation. Reuse in agriculture, on the other hand, results in higher hygienic-treatment demand. More extensive treatment or dilution with fresh river-water might also be necessary to allow fish farming.

Other possible benefits from wastewater treatment, like biogas production, also restrict the choice of treatment methods, and influence investment and maintenance costs as well as amortisation.

Picture 8_4: Sludge from an septic tank in India – the black colour of the sludge indicates anaerobic condition

9 DEWATS – technical components

This chapter introduces the technical-treatment components of DEWATS, which correspond to the DEWATS criteria defined in chapter 7.

After a brief overview and comparison of the different technologies, detailed sections on each component explain the specifics of design, applied-treatment processes, and start-up considerations as well as operation and maintenance procedures.

9.1 Overview of DEWATS components

DEWATS is based on four treatment systems:

- Sedimentation and primary treatment in sedimentation ponds, septic tanks or Imhoff tanks
- Secondary anaerobic treatment in fixed-bed filters or baffled septic tanks (baffled reactors)
- Secondary and tertiary aerobic/anaerobic treatment in constructed wetlands (subsurface flow filters)
- Secondary and tertiary aerobic/anaerobic treatment in ponds

Components are combined in accordance with the wastewater influent and the required effluent quality. Hybrid systems or a combination of secondary on-site treatment and tertiary co-operative treatment is also possible.

The following treatment components are discussed in further detail in the ensuing chapters:
Grease traps and grit chambers are beneficial for wastewater from canteens and certain industries. Short retention times prevent the settling of biodegradable solids. Grit and grease must be removed frequently.

Septic tanks are the most common form of treatment. The robust system provides a combination of mechanical treatment through sedimentation and biological degradation of settled organic solids. Septic tanks are used for wastewater with a high percentage of settleable solids, typically effluent from domestic sources.

Imhoff tanks are slightly more complicated to construct than septic tanks, but provide a fresher effluent when de-sludged frequently. Imhoff tanks are preferred when post-treatment takes place near residential houses, in open ponds or constructed wetlands of vertical flow type.

Anaerobic filters combine mechanical solids-removal with digestion of dissolved organics. By providing filter surfaces for biological activity, increased contact between new wastewater and active bacteria results in effective digestion. Anaerobic filters are used for wastewater with a low percentage of suspended solids (for example, after primary treatment in septic tanks), and narrow COD/BOD ratioUpstream Anaerobic Sludge Blanket (UASB) reactors utilise a floating sludge blanket as a biologically active filter medium.

Baffled septic tanks function as multi-chamber septic tanks. They increase biological degradation by forcing the wastewater though active sludge beneath chamber-separating baffles. All baffled septic tanks are suitable for all kinds of wastewater, they are most appropriate for wastewater with a high percentage of non-settleable suspended solids and narrow COD/BOD ratio.

Fully mixed digesters provide anaerobic treatment of wastewater with higher organic load. In the process, biogas is produced as a useful by-product.

Trickling filters treat wastewater aerobically by letting it trickle over biologically active filter surfaces.

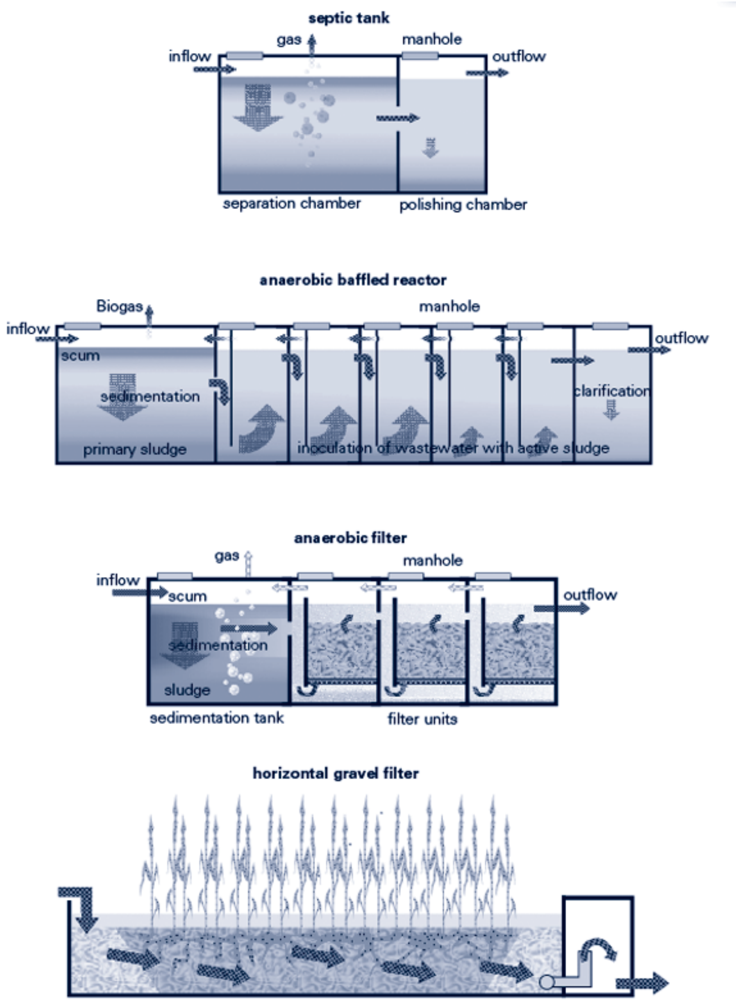
Horizontal gravel filters are sub-surface, flow constructed wetlands, which provide effective, facultative treatment and filtration, while allowing for appealing landscaping. Constructed wetlands are used for wastewater with a low percentage of suspended solids and COD concentrations below 500 mg/l.

Pond systems are the ideal form of DEWATS treatment – if the required space is available. Anaerobic ponds are deep and highly loaded with organics. Depending on the retention time, digestion of sludge only or the complete wastewater is possible. Facultative and anaerobic ponds may be charged with strong wastewater, however, bad odour cannot be avoided reliably with high loading rates. Aerobic ponds are large and shallow – they provide oxygen via the pond surface for aerobic treatment. Wastewater for treatment in aerobic ponds should have a BOD_5 content below 300 mg/l. Pond systems can be combined with certain types of vegetation, creating aquatic plant systems with additional benefits.

Special provisions are usually required for the treatment of industrial wastewater before standardised DEWATS designs can be applied. These may include open settlers for the daily removal of fruit waste from canning factories, buffer tanks for mixing varying flows from milk-processing plants, or grease traps or neutralisation pits to balance the pH of the influent. In these cases, standard DEWATS components are applicable only after such pre-treatment steps have been taken.

Despite their reliability and impressive treatment performance, such well-known and proven systems as UASB, trickling and vertical filters, rotating discs, etc. are not considered to be DEWATS because they require careful and skilled attendance.

Most treatment processes applied in conventional, large-scale treatment plants do not meet the DEWATS criteria. The activated-sludge process, the fluidised-bed reactor, aerated or chemical flocculation and all kinds of controlled re-circulation of wastewater fall within this category. Regular or continuous re-circulation might be acceptable if the pumps that are used cannot be switched off because they also act as transportation pumps.



Picture 9_1:
Treatment systems considered to be suitable for decentralised dissemination

type	kind of treatment	used for type of wastewater	advantages	disadvantages
septic tank	sedimentation, sludge stabilisation	wastewater with settleable solids, especially domestic	simple, durable, little space because of being under-ground	low treatment efficiency, effluent not odourless
Imhoff tank	sedimentation, sludge stabilisation	wastewater with settleable solids, especially domestic	durable, little space because of being under-ground, odourless effluent	less simple than septic tank, needs very regular desludging
anaerobic filter	anaerobic degradation of suspended and dissolved solids	pre-settled domestic and industrial wastewater with narrow COD/BOD ratio	simple and fairly durable if well constructed and waste-water has been properly pre-treated, high treatment efficiency, little permanent space required because of being underground	costly to construct because of special filter material, blockage of filter possible, effluent smells slightly despite high treatment efficiency
baffled septic tank	anaerobic degradation of suspended and dissolved solids	pre-settled domestic and industrial wastewater with narrow COD/BOD ratio, suitable for strong industrial wastewater	simple and durable, high treatment efficiency, little permanent space required because of being underground, hardly any blockage, relatively cheap compared to anaerobic filter	requires larger space for construction, less efficient with weak wastewater, longer start-up phase than anaerobic filter
horizontal gravel filter	aerobic-facultative-anaerobic degradation of dissolved and fine suspended solids, pathogen removal	suitable for domestic and weak industrial wastewater where settleable solids and most suspended solids are already removed by pre-treatment	high treatment efficiency when properly construc-ted, pleasant landscaping possible, no wastewater above ground, can be cheap to construct if filter material is available at site, no nui-sance of odour	high permanent-space requirement, costly if right qualtity of gravel not available, great know-ledge and care required during construction, intensive maintenance and supervision during first 1-2 years
anaerobic pond	sedimentation, anaerobic degradation and sludge stabilisation	strong and medium industrial wastewater	simple in construction, flexible in respect to degree of treatment, little maintenace	wastewater pond occu-pies open land, there is always some odour, can even be stinky, mosqui-toes are difficult to control
aerobic pond	aerobic degradation, pathogen removal	weak, mostly pre-treated wastewater from domestic and industrial sources	simple in construction, reliable in performance if properydimensioned, high pathogen removal rate, can be used to create an almost natural enviroment, fish farming possible when large in size and low loaded	large permanent space requirement, mosquitoes and odour can become a nuisance if undersized near residential areas, algae can raise effluent BOD

Table 19:
Pros and Cons of DEWATS

Admittedly, these self-imposed restraints on DEWATS can, in practice, impact the quality of the effluent. But this need not be the case if there is sufficient space for the plant. Measures to discharge effluent of acceptable quality include:

- provision of sufficient space at the source of pollution
- pre-treatment at source and post treatment where sufficient land is available
- pre-treatment at source and post treatment in co-operation with others
- accepting an effluent with higher pollution load
- restricting wastewater-producing activities at this particular site
- connection to a central treatment plant via a sewage line

The permanent dilution of wastewater or the installation of a highly mechanised, "modern" treatment plant remain theoretical options – experience shows that such processes are chronically afflicted by irregular operation.

Picture 9_2: One of too many non-aerating aerators

Space requirements

Depending on the total volume and the nature of the wastewater and its temperature, the following values may indicate permanent area requirements for setting up a treatment plant:

Septic tank, Imhoff tank:	0.5 m²/m³ daily flow
Anaerobic filter, Baffled septic tank:	1 m²/m³ daily flow
Constructed wetland:	30 m²/m³ daily flow
Anaerobic ponds:	4 m²/m³ daily flow
Facultative aerobic ponds:	25 m²/m³ daily flow

These values are approximations for wastewater of typical strength; land requirements increase with wastewater of higher pollution load. Land use can be minimised if closed anaerobic systems are applied, as they are usually constructed underground. The area for sludge-drying beds may require an additional 0.1 to 10 m^2/m^3 daily flow, depending on the wastewater quality and desludging intervals.

Performance

Treatment quality depends on the nature of the influent and boundary conditions like temperature. BOD-removal rates are generally within these ranges:
25 to 50% for septic tanks and Imhoff tanks
70 to 90% for anaerobic filters and baffled septic tanks
70 to 95% for constructed-wetland and pond systems

The treatment efficiency of the different components and the required effluent quality decide the choice of treatment system. For example, septic tanks alone are not adequate for direct discharge into surface waters, but may suit treatment on land where the groundwater table is low and odour is not likely to be a nuisance. Assuming a discharge limit of 50 mg/l BOD, the anaerobic filter in combination with a septic tank may treat wastewater of 300 mg/l BOD without further treatment. Stronger wastewater would require a constructed-wetland or pond system for final treatment. Perhaps even long-way open discharge channels are sufficient to provide the necessary additional treatment.

Based on local conditions, many other possibilities for cheaper treatment systems may exist – all options must be considered. Expert knowledge is needed to evaluate such possibilities; wastewater-sample analysis should be campulsory.

Substantial removal of nitrogen requires a mix of aerobic and anaerobic treatment, only provided by constructed wetlands and ponds. In closed anaerobic-tank systems of the DEWATS-type, nitrogen forms to ammonia. The effluent is a good fertiliser but causes algae growth and is toxic to fish if released into surface waters.

Phosphorus is a good fertiliser and, therefore, dangerous in rivers and lakes. Phosphorus removal in DEWATS is limited – as like in most treatment plants. Constructed wetlands with filter media containing iron or aluminium compounds present one form of removal. Furthermore phosphorus can be accumulated by sedimentation or fixed in bacterial mass, although it can hardly be removed from the sludge or be transformed into a less-harmless state.

Pathogen control

Like all other modern wastewater-treatment plants, DEWATS systems are not focused on pathogen control. Pathogen removal increases with longer retention times, but treatment plants proudly function on short HRTs.

The WHO guidelines and other independent surveys describe the transmission of worm infections as the greatest risk associated with wastewater. Worm eggs or helminths are, for the most part, removed from effluent by sedimentation and accumulate in the bottom sludge. The long retention times in septic tanks and anaerobic filters of 1 to 3 years provide sufficient protection against helminths infection; frequent sludge removal is discouraged due to increased health risks.

Although many bacteria and viruses are destroyed during treatment, the concentrations in the effluent of anaerobic filters and septic tanks are still infectious. Higher pathogen removal rates are reported from constructed wetlands and shallow aerobic ponds; the effect is attributed to longer retention times, exposure to UV rays in ponds, and various bio-chemical interactions in constructed wetlands. The pathogen-removal rates of these systems are, in fact, higher than in conventional municipal treatment plants.

Chlorination can be used for pathogen control. Simple devices with automatic dosing may be added before final discharge. However, the use of chlorine should be limited to cases of high risk, such as hospital wastewaters during an epidemic. Permanent chlorination should be avoided because it not only kills pathogens but also destroys other bacteria and protozoa, which are responsible for the self-purification effect of receiving waters.

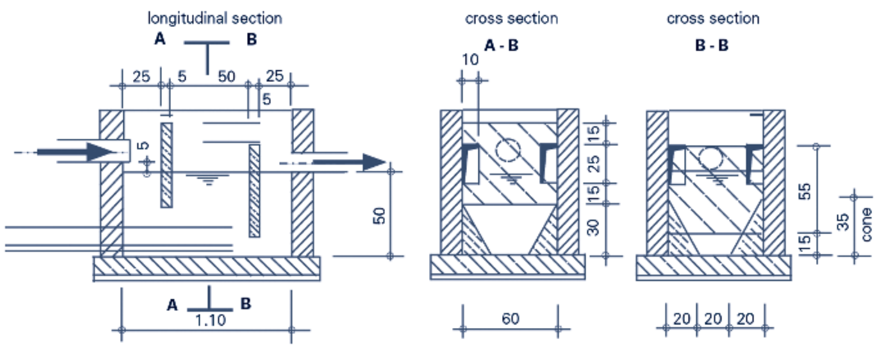
9.2 Grease trap and grit chamber

If a septic tank is provided, DEWATS normally do not require grease traps or grit chambers for domestic wastewater. Whenever possible they should be avoided altogether because grease and grit must be removed, at least once a week. However, for canteens or certain industrial wastewaters it may be advisable to separate grit and grease before the septic tank.

The function of grease and grit chambers is comparable to that of septic tanks; light matter should float and heavy matter should sink to the bottom. The difference is that bio-degradable solids should have no time to settle. Retention times for grit chambers are short, therefore, – only about three minutes. The use of masonry structures is not appropriate, especially in the case of minor flows.

A conical trough allows slow flow at a large surface for grease floatation and fast flow at the narrow bottom, which allows only heavy and coarse grit to settle. The water surface is protected from the turbulence of the inflow by a baffle; the outlet is near the bottom.

Picture 9_3: Principal design of combined grease trap and grit chamber. Accumulating grease, oil and grit should be removed daily, or at least weekly. If this can not be assured, an oversized septic tank is preferable to receive grit and grease

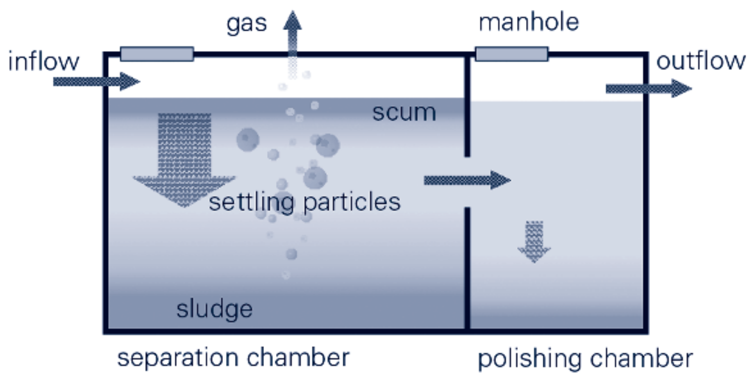


9.2.1 Septic tank

The septic tank is the most common, small scale and decentralised treatment plant, worldwide. It is compact, robust and extremely efficient when compared with the cost of constructing. It is basically a sedimentation tank in which settled sludge is stabilised by anaerobic digestion. Dissolved and suspended matter leaves the tank more or less untreated.

Two treatment principles, namely the mechanical treatment by sedimentation and the biological treatment by contact between fresh wastewater and active sludge, compete with each other in the septic tank. Optimal sedimentation takes place when the flow is smooth and undisturbed. Biological treatment is optimised by quick and intensive contact between new inflow and old sludge, particularly when the flow is turbulent. How the influent enters and flows through the tank decides which treatment effect predominates.

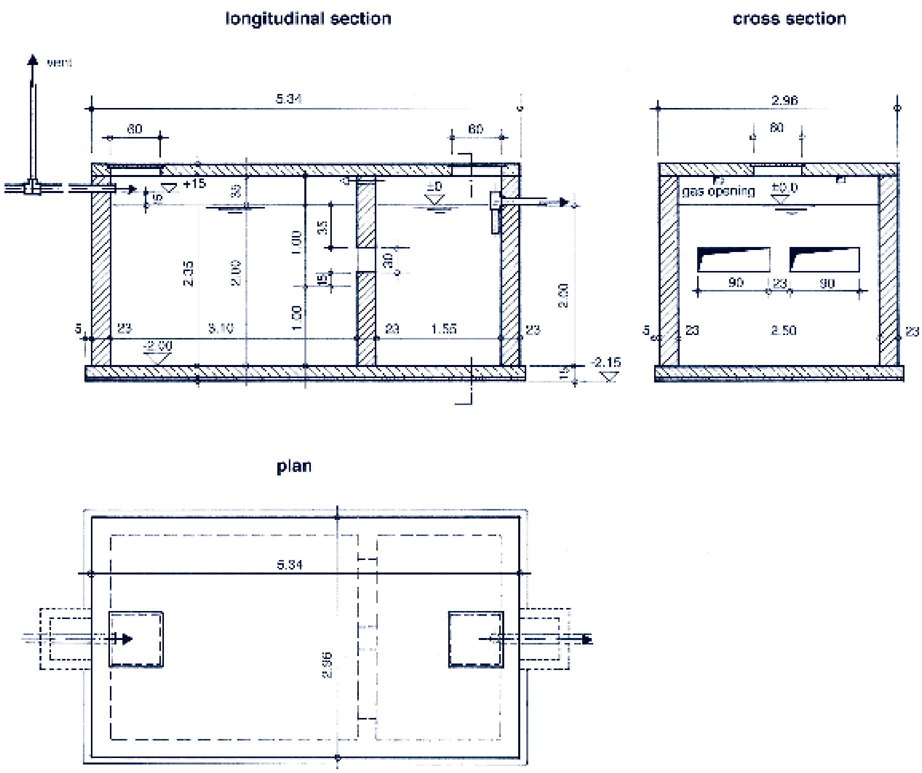
With smooth and undisturbed flow, the supernatant (the water remaining after settleable solids have separated) leaves the septic tank rather fresh and odourless, implying that degradation has not yet started. With turbulent flow, the degradation of suspended and dissolved solids starts immediately because of the intensive contact between fresh and already active substrate. However, as turbulence hinders sedimentation, more suspended solids are discharged with the effluent, resulting in odours because active solids, which are not completely fermented, leave the tank.



Picture 9_4:
Flow principle of the septic tank. Most sludge and scum is retained in the first chamber; the second chamber contains only a little sludge, which allows the water to flow without disturbance from rising gas bubbles

Domestic wastewater normally forms a heavy scum near the inlet. This consists of matter lighter than water, such as fat, grease, wood-chips, hair or any floating plastics. A larger portion of the floating scum also consists of sludge particles, which are released from the bottom and driven to the top by treatment gases. New sludge from below lifts the older scum particles above the water surface where they dry and become lighter. The accumulated scum must be removed regularly, at least every third year. Scum does not harm the treatment process as such, but it does occupy tank volume.

A septic tank consists of a minimum of two, sometimes three compartments. The compartment walls extend 15 cm above the liquid level. They may also be used as bearing walls for the covering slab if some openings for internal gas exchange are provided.



Picture 9_5:
The septic tank. The dimensions have been calculated for 13 m³ of domestic wastewater per day

The first compartment occupies about two-thirds of the septic-tank volume, allowing for most of the sludge and scum accumulation. The following chamber(s) are provided to calm the turbulent liquid. They are all the same size and make up the remainder of the volume. All chambers are normally the same depth. The depth from the outlet level to the bottom should be between 1.50 m and 2.50 m. The first chamber is sometimes deeper.

The size of the first chamber is calculated to be at least twice the accumulating sludge volume. The sludge volume depends on the settleable solids content of the influent and on desludging intervals (Picture 10_5). Most countries provide a National Standard for tank volume per domestic user.

The SS removal rate drops drastically when accumulated sludge fills more than two-thirds of the tank. This must be avoided, especially in cases where the effluent is treated further in a sand or gravel filter.

"Irregular emptying of septic tanks leads to irreversible clogging of the infiltration bed; rather than renewing the bed, most owners bypass it and divert the tank's effluent to surface drains."[37]

37 See: Alearts et all, 1990

For domestic sewage, the accumulating sludge volume can be calculated with 0.1 L/cap×d. When desludging intervals are longer than two years, the sludge volume may be reduced to 0.08 L/cap×d, as sludge compacts with time (see Picture 10_5).

The inlet may dive down inside the tank, below the assumed lowest level of the scum – or may be above the water level when the inlet pipe is used to evacuate gas. A septic tank is basically a biogas plant, without biogas use. Gas accumulates inside the tank above the liquid, from where it should be able to escape into the air. The ventilation pipe for digester gases should end outside buildings, at an elevation above roof level. Open fire should be avoided when opening the septic tank for cleaning.

The compartments are connected by simple wall openings situated above the highest sludge level and below the lowest level of the scum. For domestic wastewater, the top of the opening should be 30 cm below outlet level, its base at least half the water depth above the floor. The openings should be equally distributed across the width of the tank, in order to minimise turbulence. A slot, spanning the full width of the tank, is ideal for reducing velocity and turbulence.

The outlet has a T-joint, the lower arm of which dives 30 cm below the water level. With this design, foul gas trapped in the tank enters the sewage line from where it must be ventilated safely. If ventilation cannot be guaranteed, an elbow must to be used at the outlet to prevent the gas from entering the outlet pipe. There should be manholes in the cover slab; one each above inlet and outlet and one at each partition wall, preferably at the inlet of each compartment. The manholes should permit water sampling from each compartment.

Septic tanks were originally designed for domestic wastewater. They are also suitable for other wastewater of similar properties, particularly those that contain a substantial portion of settleable solids.

The treatment efficiency of a septic tank ranges from 25% to 50% COD removal. It serves as rough, primary treatment, prior to secondary or even tertiary treatment. Post-treatment may be provided in ponds or ground filters. In the latter case, regular desludging of septic tanks is mandatory. A septic tank may also be integrated into an anaerobic filter or as the first section of a baffled reactor. Septic tanks are suitable as individual on-site pre-treatment units for community sewer systems because the diameter of sewerage can be smaller when settleable solids have been removed on-site.

Starting phase and maintenance

A septic tank may be used immediately; it does not require special arrangements before usage. However, sludge digestion begins only after several days. Regular desludging is required every one to three years. When removing the sludge, some immature (still-active) sludge should be left inside the tank to enable continuous decomposition of newly settling solids; it is not necessary to remove the liquid. This means, if the sludge is removed by pumping, the pump head should be brought down to the very bottom. Adequate handling and treatment of septic sludge is discussed in detail in chapter 11. The septic tank's surroundings should be kept free of plants to prevent roots from growing in the pipelines and control chambers.

Calculating dimensions

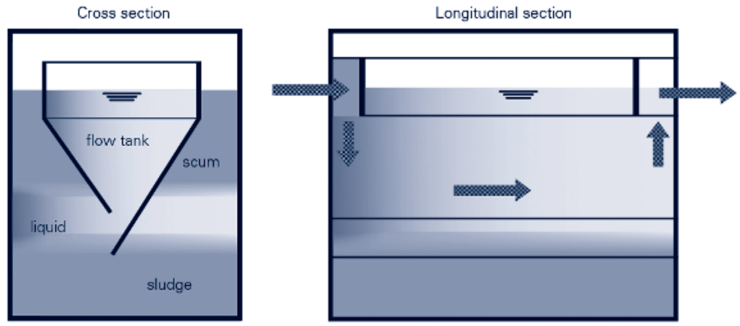
Approximately 80 to 100 l should be provided per domestic user. For exact calculation, or for wastewater from non-domestic sources, the formula applied in the computer spreadsheet (Table 14) may be used.

9.2.2 Imhoff tank

Imhoff or Emscher tanks are typically used for domestic or mixed wastewater flows above 3 m^3/d when the effluent receives further treatment above the ground and, therefore, should not stink – as may be the case with septic tanks. The Imhoff tank effectively separates fresh influent from bottom sludge.

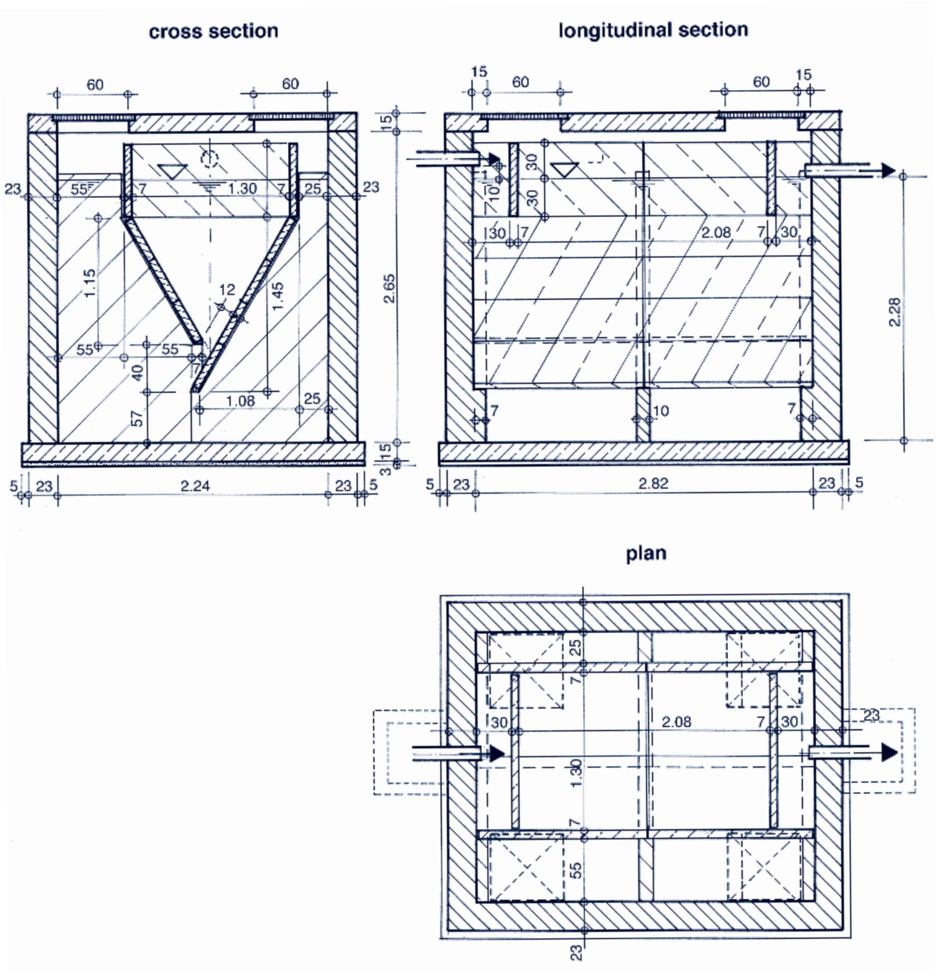
The tank consists of a settling compartment above the digestion chamber. Funnel-like baffle walls prevent up-flowing foul-sludge particles from mixing with the effluent and causing turbulence. The effluent remains fresh and odourless because the suspended and dissolved solids do not come into contact with the active sludge and turn sour and foul. Retention time should not be much more than 2 hours during peak flow, otherwise this effect jeopardised.

When sludge ferments at the bottom, the sludge particles get attached to foul – gas bubbles and start floating upwards. The up-flowing sludge particles assemble outside the conical walls and form an accumulating scum layer, which grows continuously downwards. When the slots – through which settling particles should fall into the lower compartment – are closed, the treatment effect is reduced to that of a undersized septic tank. Sludge and scum, therefore, must be removed at appropriate intervals.



Picture 9_6: Flow principle of the Imhoff tank. The water passes quickly through the flow tank, undisturbed by rising gas bubbles; the water does not mix with "ripe" water or sludge

The inlet and outlet pipes are the same shape as those in septic tanks. Pipe ventilation must be provided, as Imhoff tanks also produce biogas. Additional baffles to reduce velocity at the inlet – and to retain suspended matter at the outlet – are advantageous. The upper part of the funnel-shaped baffles is vertical for 30 cm above and 30 cm below the water surface. The shape of an Imhoff tank may be cylindrical; the funnel however, should always be rectangular, in order to leave adequate space outside the funnel for scum removal. The funnel structure may consist of pre-fabricated ferro-cement. Treatment efficiency lies in the range of 25 to 50% COD reduction.



Picture 9_7:
Imhoff tank. Dimensions have been calculated for 25 m³ of domestic wastewater per day

Starting Phase and Maintenance

As with septic tanks, no special start-up phase is required. Desludging is necessary at regular intervals. Sludge should be removed from the bottom of the tank by pumping or hydraulic pressure pipes, withdrawing only fully digested substrate and leaving some active sludge behind for maintaining bacterial activity. Best practice in the removal, handling and treatment of sludge is discussed in detail in chapter 11.

Scum must be removed before it grows enough to close the slots between the upper and lower compartments. Should this happen, gas bubbles appearing in rows on the water surface above the slots indicate excessive scum accumulation. Scum should be removed before sludge removal; the liquid may remain inside the tank.

Calculating dimensions

The upper compartment, inside the funnel walls, should be designed for 2 h HRT at peak flow, and the hydraulic load should be less than 1.5 m^3/h per 1 m^2 surface area. The sludge compartment below the slots should be calculated to retain 2.5 litres of sludge per kg BOD reduced per day for short desludging intervals. For longer intervals please refer to the corresponding spreadsheet (Table 26).

For domestic wastewater and desludging intervals of one year, the upper compartment should have a volume of approximately 50 l per user and the sludge compartment below the slots should have a volume of approximately 120 litres per user. This is only a rule of thumb; for more detailed calculations, or for wastewater from non-domestic sources, please refer to the spreadsheet.

9.2.3 Anaerobic Filter

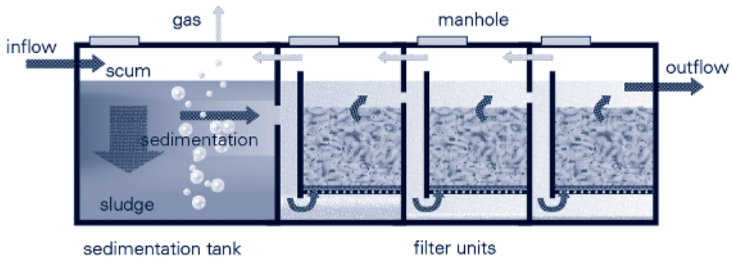
The dominant principle of both the septic and Imhoff tanks is sedimentation combined with sludge digestion. The anaerobic filter, also known as a fixed-bed or fixed-film reactor, is different in that it also includes the treatment of non-settleable and dissolved solids by bringing them into close contact with a surplus of active bacterial mass.

"Hungry" bacteria digest the dispersed or dissolved organic matter within a short retention time. Most of the bacteria are immobile; they attach themselves to solid particles or, for example, the reactor walls. Filter material, such as gravel, rocks, cinder or specially formed plastic shapes, provide additional surface area for bacteria to settle. By forcing the fresh wastewater to flow through this material, intensive contact with active bacteria is established; the larger the surface for bacterial growth, the quicker the digestion. Good filter material provides 90 to 300 m^2 surface area per m^3 of occupied reactor volume. Rough surfaces provide a larger area, at least in the starting phase; the bacterial "lawn" or "film" that grows on the filter mass quickly closes the smaller grooves and holes.

Picture 9_8:
Floating filter balls made of plastic. When bacteria film becomes too heavy, the balls turn over and discharge their load. The filter medium has successfully been used for tofu wastewater by HRIEE in Zheijiang Province in China.

Anaerobic filters are very reliable and robust. Experience shows, however, that between 25 to 30% of the total filter mass may be inactive due to clogging. While a cinder or rock filter may not-completely become, reduced treatment blocked efficiency is indicative of clogging in some parts. Sand or gravel filters may block up completely due to smaller pore size.

Clogging happens when wastewater finds a channelled way through just a few open pores; eventually, the lessused voids clog and higher flow velocities result in the few occur open remaining. This leads to reduced retention time active bacteria is washed away.

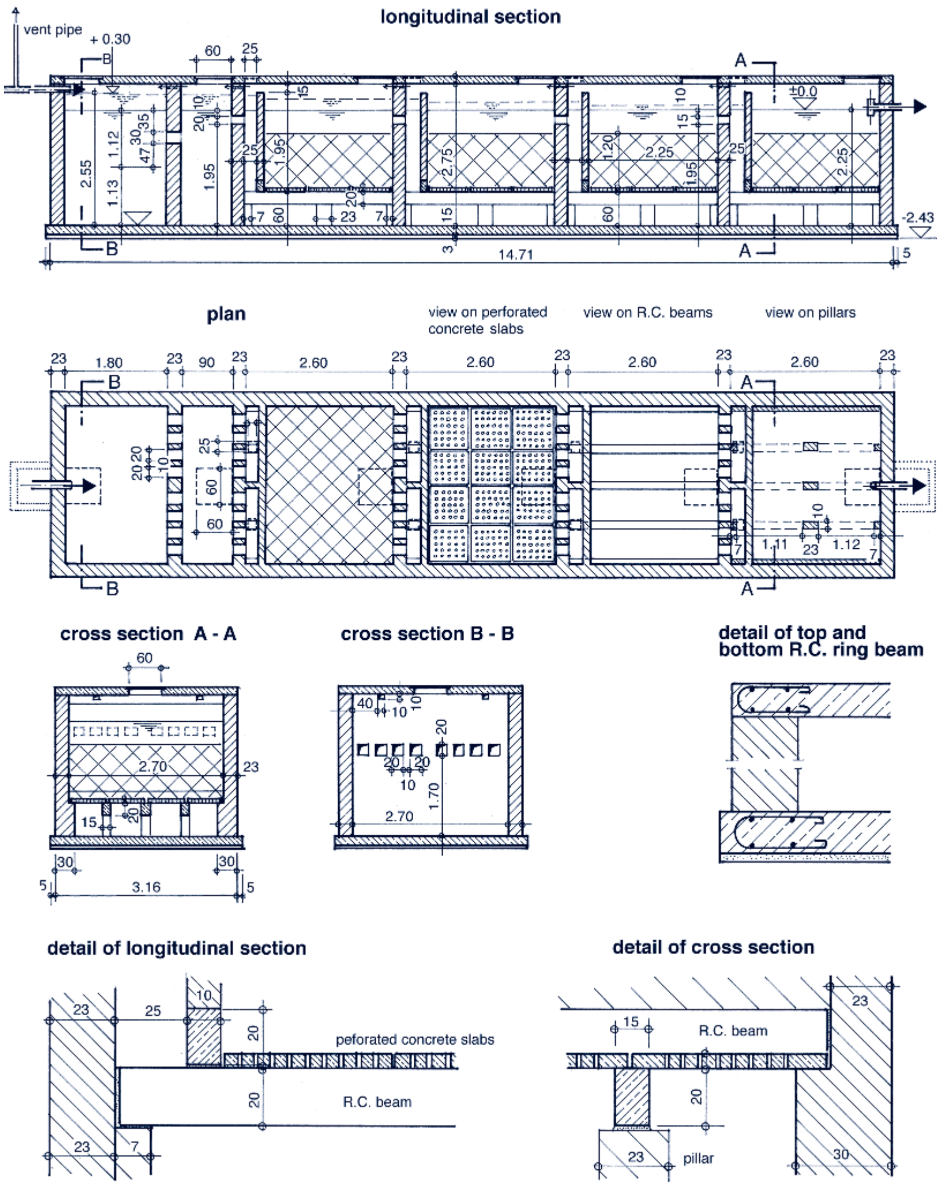


Picture 9_9: Flow principle of anaerobic up-flow filter. Most suspended solids should be retained in the septic tank. Filter bacteria consume dissolved and dispersed solids. Anaerobic filters may also be designed for down-flow

When the bacterial film becomes too thick it must be removed. This may be done either by back-washing or by removing the filter mass for cleaning outside the reactor.

The treatment efficiency of well-operated anaerobic filters ranges between 70 to 90% BOD removal. They are suitable for domestic wastewater and all industrial wastewater with low suspended-solids content. Pre-treatment in settlers or septic tanks may be necessary to eliminate larger solids before the wastewater enters the filter.

Anaerobic filters may be operated as down-flow or up-flow systems. The up-flow system is normally preferred because there is less risk of washing out active bacteria. On the other hand, flushing the filter – or cleaning – is easier in down-flow systems. A combination of up-flow and down-flow chambers is also possible.

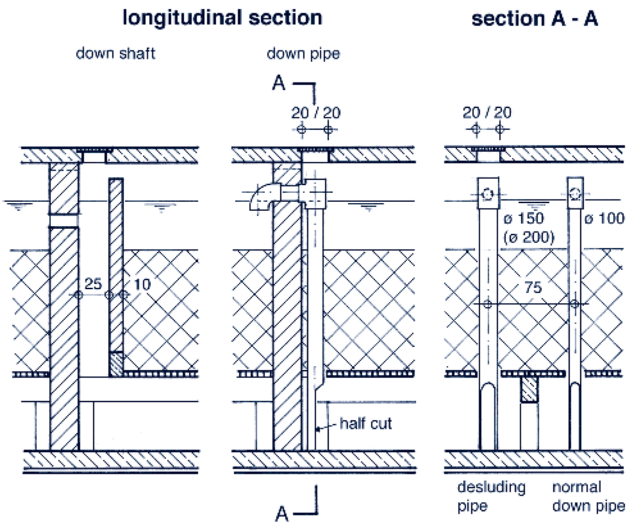


Picture 9_10:
Anaerobic filter – dimensions have been calculated for 25 m³ domestic wastewater per day

An important design criterion is the equal distribution of wastewater across the filter area. Equal distribution is facilitated by providing adequate free-flow space across the full width before and after the filter. This is why full-width down-flow shafts are preferred to down-flow pipes. The length of the filter chamber should not be greater than the depth of the water.

For smaller and simple structures, the filter mass consists of cinder (5 to 15 cm in diameter) or rocks (5 to 10 cm in diameter), which are – bedded on perforated-concrete slabs. The filter starts with a layer of sized rocks at the bottom. The slabs rests on beams, which are parallel to the direction of flow, approximately 50 to 60 cm above the ground slab. Pipes of at least 15 cm diameter, or down-shafts over the full width, permit desludging at the bottom with the help of pumps from the top. In case the sludge-drying beds are located directly beside the filter, sludge may also be drawn via hydraulic-pressure pipes. Head losses of 30 to 50 cm have to be considered.

Biogas utilisation may be considered in case of BOD concentration > 1,000 mg/l; this requires completely gas-tight construction and provisions for collection, storage and use.



Picture 9_11: Down-shaft and down-pipes – both systems may be applied alternatively in anaerobic filters and baffled septic tanks

Starting phase and maintenance

Since the treatment process depends on a surplus of active bacterial mass, active sludge (for example, from septic tanks) should be sprayed on the filter material before continuous operation is started. If possible, start with only a quarter of the daily flow, and increase the flow slowly over three months. As this might not be possible in practice, full treatment is valikely to be operating at full capacity until approximately six to nine months later.

As with septic tanks, desludging should be done at regular intervals. Where possible, the filter should be back-washed before sludge removal. Adequate removal, handling and treatment of sludge is discussed in detail in chapter 11. The filter should be cleaned when efficiency declines.

Calculating dimensions

Organic-load limits between range 4 to 5 kg COD/$m^3 \times d$. The hydraulic retention time compared to the tank volume should between one and a half and two days. For exact calculation, please refer to the spreadsheet (Table 9). For domestic wastewater, constructed gross digester volume (voids plus filter mass) may be estimated at 0.5 m^3/capita; for smaller units it is closer to 1 m^3/capita.

9.3 UASB

The UASB system is not considered a DEWATS technology. However, an understanding of the principle on which it functions may improve ones's understanding of the baffled septic tank.

In a UASB reactor (Upstream Anaerobic Sludge Blanket reactor) the upstream velocity and settling speed of the sludge is in equilibrium and forms a locally rather stable, suspended sludge blanket in the lower part of the digester. This sludge blanket of suspended active sludge acts as a filter medium. After some weeks of maturation, granular sludge forms and improves the physical stability and filter capacity of the sludge blanket.

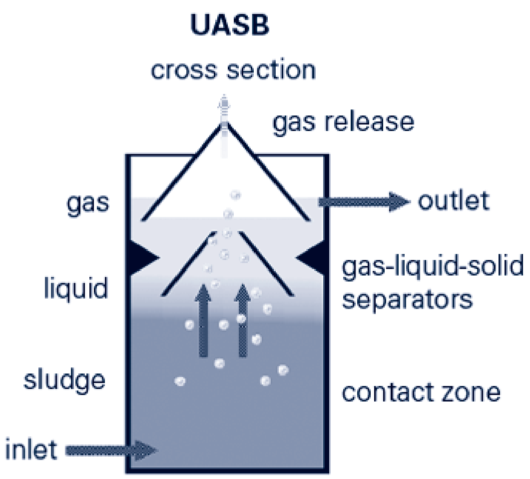
To keep the blanket in its proper position, the hydraulic load must correspond with the upstream velocity and with the organic load. The latter is responsible for the development of new sludge. So the flow rate must be controlled and regulated in accordance with fluctuations of the organic load. Generally, the fluctuation of inflow is high in smaller units and regulating wastewater flow is not possible. Furthermore, it is not possible to stabilise the process by increasing the hydraulic retention time without lowering the upstream velocity. Although the system is simple to build, these operational difficulties render it unsuitable for DEWATS, particularly for relatively weak, domestic wastewater.

Fully controlled UASBs are used for relatively strong industrial wastewater. Slanting baffles (similar to the Imhoff tank) help to separate gas bubbles from solids, whereby solids are also separated from the up-streaming liquid. These baffles are called 3-phase separators. Biogas can be collected and used.

UASB reactors require several months to mature – to develop sufficient granular sludge to provide treatment. Granular sludge looks like big flocs of dust; bacterial slime forms chains, which coagulate into flocs or granules. High organic loading, in connection with lower hydraulic loading, speeds up the granulation process in the starting phase. Since higher velocities are required to lift sludge granules compared to single sludge particles, the sludge blanket remains relatively stable.

Starting phase, maintenance and calculating dimensions

The UASB does not belong to DEWATS. Details of how to operate and calculate its dimensions are deliberately omitted from this handbook so that readers don't gain the impression that the UASB can be built and operated under DEWATS conditions.



Picture 9_12: Flow principle of UASB reactors. Up-streaming water and gas-driven sludge particles hit baffles, which cause to separate of gas, solids and liquid

9.3.1 Baffled septic tank

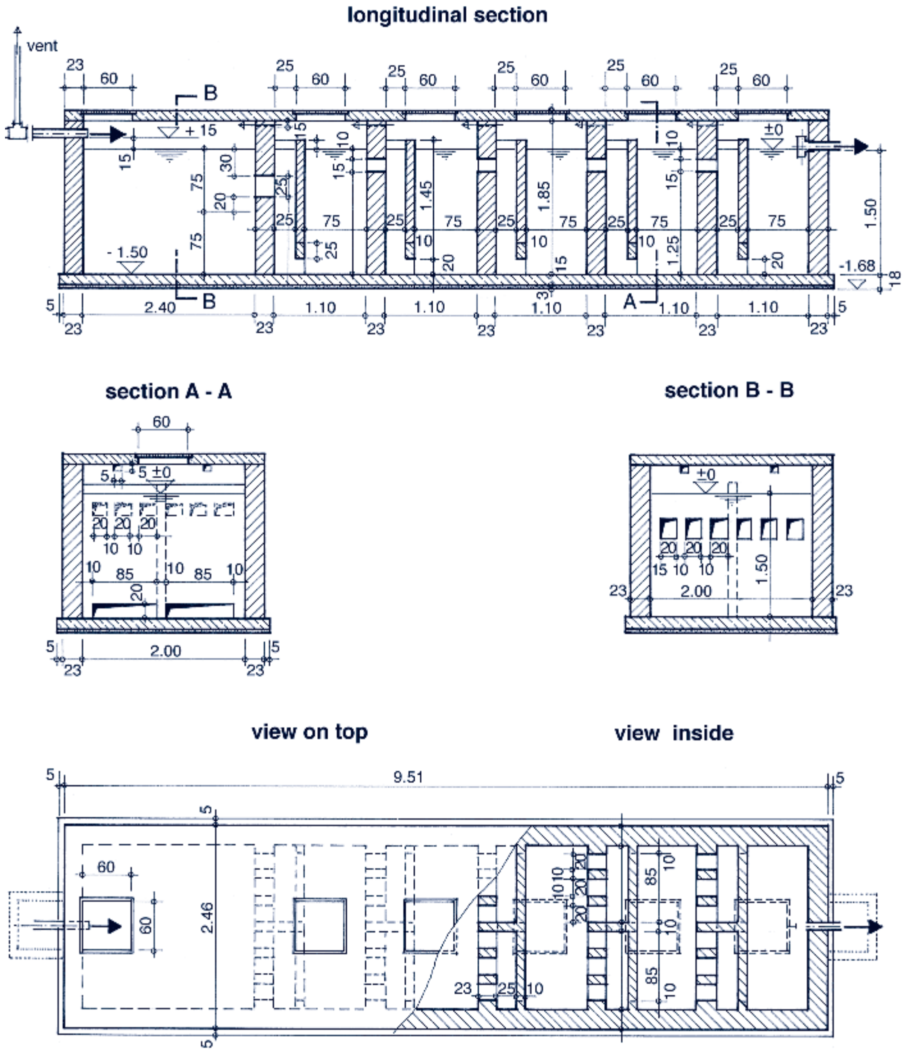
The baffled septic tank, also known as the "baffled reactor", can be considered as the DEWATS version of the UASB system. It is, in fact, a combination of several anaerobic-process principles: the septic tank, the fluidised bed reactor and the UASB.

The up-flow velocity of the baffled septic tank, which should never be more than 1 m/h, limits its design. Based on a given hydraulic retention time, the up-flow velocity increases in direct relation to the reactor height. The reactor height, therefore, can not be used as a variable parameter to achieve the required HRT. The limited upstream velocity results in large but shallow tanks, making the system uneconomical for larger plants. This is why baffled septic tanks are not very well-known or properly researched.

However, the baffled septic tank is ideal for DEWATS because it is simple to build and simple to operate. Hydraulic and organic shock loads have little effect on treatment efficiency.

Picture 9_13: Flow principle of a baffled septic tank. Incoming waste-water is forced to pass through active-bacteria sludge in each compartment. The settler at the front prevents larger solids from entering the baffled section

The main difference to the UASB is that it is not necessary for the sludge blanket to float; it may rest at the bottom. Three-phase separators are also unnecessary because active sludge washed out from one chamber is trapped in the next. Tanks in series also help to digest difficult degradable substances, predominantly in the later chambers after easily degradable matter has been digested in the earlier ones. The baffled septic tank consists of at least four chambers in series. But practical experience shows that treatment efficiency does not increase with more than six chambers. The last chamber can incorporate a filter in its upper part, in order to retain remaining solid particles; alternatively, a settler for post-treatment can follow the baffled septic tank (Picture 9_39).



Picture 9_14:
Baffled septic tank. Dimensions have been calculated for 25 m³ domestic wastewater per day

Equal distribution of inflow, and extensive contact between new and old substrate are important process features. Unlike in the Imhoff tank, the fresh influent is immediately mixed – and, thereby, inoculated – with the active sludge in the reactor, to begin digestion. The wastewater flows from bottom to top with the effect that sludge particles settle against the up-stream of the liquid, providing intensive contact between resident sludge and newly incoming liquid.

The DEWATS version of the baffled septic tank does not have a rack or screen. A settling chamber is used to separate the larger solids before the wastewater continues to a series of up-flow chambers. Between chambers the water flow is directed to the bottom of the next chamber by baffle walls that form a down-shaft, or by down-pipes that are placed on the partition walls. Although down-pipes reduce the total digester length (and the cost) down-shafts are preferable of better flow distribution.

The wastewater that enters a tank should be distributed over the floor area as evenly as possible. This is facilitated by relatively short compartments (length < 50% to 60% of the height) or, in the case of down-pipes, a distance of less than 75 cm between pipes. In larger plants, when longer compartments are required, down-pipe outlets (as well as down-shafts) should reach to the centre of the floor area.

The outlet of each chamber (particularly the last one) should be placed slightly below the water surface to retain possible scum. Although not common practice, baffled septic tanks can be equipped with three-phase separators – in the form of slanting baffles in the upper third of the tank.

The baffled septic tank is suitable for treating all kinds of wastewater with BOD above BOD < 150 mg/l. Although its efficiency increases with higher organic loading, it is also well-suited for domestic wastewater. There is relatively little experience with baffled reactors because the system is only used in smaller units. As a highly efficient modification of the less-efficient septic tank, baffled septic tanks combine simple and efficient operation with easy, low-cost construction. Treatment performance is in the range of 65% to 90% COD (70% to 95% BOD) removal. However, three months are required for maturation.

Starting phase and maintenance

Treatment performance depends on the availability of active-bacterial mass. Inoculation with old sludge from septic tanks shortens the start-up phase. In principle, it is advantageous to start with only a quarter of the daily flow and with a slightly stronger wastewater. The loading rate should increase slowly over three months. This provides bacteria with enough time to multiply before suspended solids are washed out. Starting with the full hydraulic load from the beginning severely delays maturation.
Like regular septic tanks, sludge must be removed at regular intervals, leaving some sludge to ensure continuous treatment efficiency. More sludge accumulates in the front than in the rear compartments. Adequate removal, handling and treatment of sludge is discussed in detail in chapter 11.

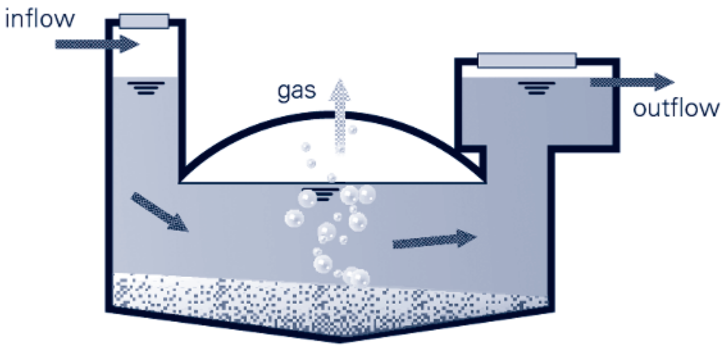
Calculating dimensions

The up-flow should not exceed 1.0 m/h. This is the most crucial parameter for dimensioning, especially with high hydraulic loading. The organic load should be below 3.0 kg COD/$m^3 \times d$. Higher loading rates are only possible at higher temperatures and for easily degradeable substrate. The HRT of the liquid fraction (i.e. above the sludge volume) should not be less than eight hours. Sludge-storage volume should be provided for 4 l/m^3 BODinflow to the settler and 1.4 l/m^3 BODremoved in the upstream tanks. For exact calculation use the formula applied in the spreadsheet (Table 28).

Picture 9_15: Baffled Reactor under construction at a factory in India

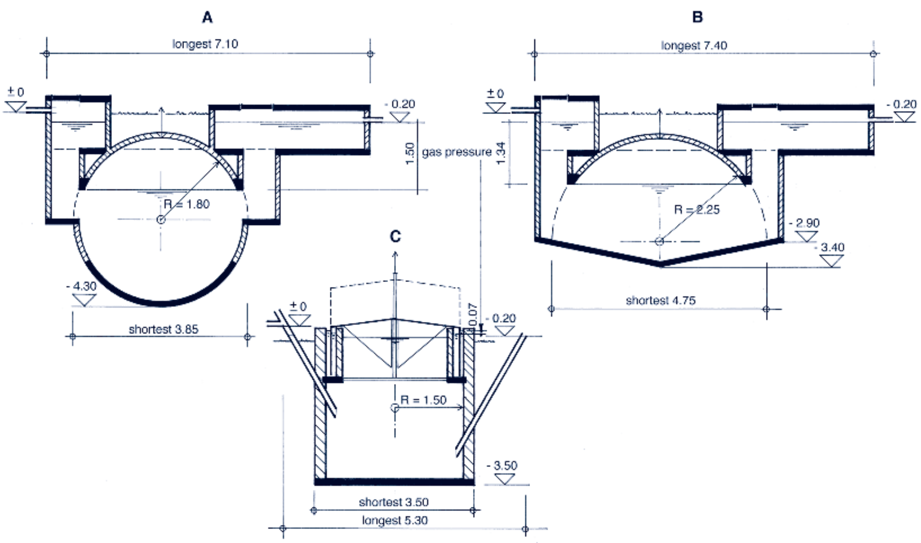
9.3.2 Fully mixed digester

The fully mixed anaerobic digester corresponds to the biogas plants, which are often used farming families in developing countries. It is suitable for rather "thick" and homogenous substrate like sludge from aerobic-treatment tanks or liquid animal excreta. For economic reasons, it is not suitable for weak-liquid wastewater because the total volume of wastewater must be agitated and kept inside the digester for the full retention time of 15 to 30 days. This results in larger digester volumes and higher construction costs. However, combining different waste sources or blackwater from several toilets can be considered.



Picture 9_16: Flow principle of the fully mixed anaerobic digester. There is little sedimentation due to viscous substrate. All substrate fractions stay inside the digester for the same period of time. The position of inlet and outlet is less important with homogeneous liquid of high TS content. Small baffles may be provided to avoid short circuiting

"Thick" viscous substrates of more than 6% total solid content do not need stirring. A digester with such a substrate can be operated for many years without desludging because only grit, but hardly any sludge, settles. Moreover, all the incoming substrate leaves the reactor after digestion. Scum formation is still possible with certain substrates. If inlet and outlet pipes are used, therefore, they should be placed at middle height. In fixed-dome digesters, the outlet should be made of a vertical shaft with the opening starting immediately below the zero-line; this will allow to some of the scum discharge.



Picture 9_17: Traditional biogas plants as fully mixed anaerobic digester. A: The ball-shaped fixed dome plant with integrated gas storage and expansion chamber. B: The half-ball-shaped fixed-dome plant. C: The floating drum plant with water seal. All three plants are designed for 600 litres substrate per day of 4% organic dry-matter content, at 25°C and HRT of 25 days. The expected gas production is 8.42 m^3/d. A comparison of the space requirements and gas pressure of all three plants indicates that floating drum plants are preferable for high gas-production rates

Since the fully mixed digester is only used for strong substrate, biogas production is high and can be used afterwards. In this case, the gascollector tank and the gas-storage tank must be gas-tight. The immediate gas outlet should be 30 cm above substrate level. Smaller units usually use the fixed dome (hydraulic-pressure) system made out of masonry structure, while larger units store the biogas in steel-drums or plastic bags.

The choice of gas-storage system will depend on the pattern of gas utilisation. Ideally, gas production should coincide with gas consumption, in time and volume. For more details, please refer to chapter 6, Biogas utilisation. An abundance of special biogas literature is also available.

Starting phase and maintenance

Starting with some active sludge from a septic tank speeds up digestion and prevents the digester from turning sour. In the rare case of this happening, the loading rate should be reduced until the pH turns neutral. It may be necessary to remove sand and grit after several years.

Calculating dimensions

The main parameter is the hydraulic retention time, which should not be less than 15 days in a hot climate and not less than 25 days in a moderately warm climate; a HRT of more than 60 days is required for highly pathogenic substrate. The gas-storage volume depends on daily gas use in relation to daily gas production. The storage capacity of gas for household use should exceed 65% of the daily gas production. Gas production is directly related to the organic fraction of the substrate. In practice, it is calculated as a fraction of the daily substrate that is fed. Experience indicates, for example, that 1 kg fresh cattle dung diluted with 1 litre of water produces 40 l of biogas. More exact calculations will be obtained by using the formulas applied in the spreadsheet Table 29.

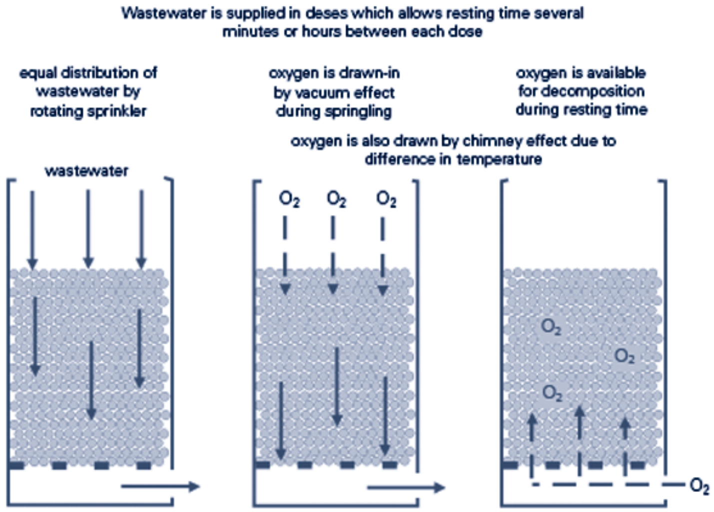
9.3.3 Trickling filter

The trickling filter is not a DEWATS solution. But some, through of as understanding of how it works will improve one's understanding of the principle of aerobic-wastewater treatment.

The trickling filter follows the same principle as the anaerobic filter, in the sense that it provides a large surface for bacteria to settle. The main difference between the two systems lies in the fact that the trickling filter works under aerobic conditions. This implies that the bacteria, which are immobilised at the filter medium, must have equal access to air and wastewater. So wastewater is dosed at intervals, providing time for air to enter the reactor during the breaks.An equal distribution of wastewater over the full surface area will utilise the filter mass most efficiently.

A trickling filter consists of:

- a dosing device
- a rotating sprinkler
- a filter body, which is ventilated both from the top and the bottom



Picture 9_18
The principle of the trickling filter

Rocks with a diameter of between 3 and 8 cm in are used as the filter medium. The outside of the filter body is closed to prevent sludge flies from escaping into the open. The filter rests above ground to allow ventilation. The bottom slab is sloped so that sludge and water inses away. The bacterial film must be flushed away regularly to remove dead sludge and to prevent clogging. High hydraulic-loading rates (> 0.8 $m^3/m^2 \times h$) have a self-flushing effect. With organic-loading rates of 1 kg BOD/$m^3 \times d$, 80% BOD removal is possible. Higher loading rates reduce efficiency.

In a 2 m-high trickling filter with a wastewater of 500 mg/l BOD, the organic-loading rate comes to:

0.8×24 hrs $\times$ 0.5 kg/m^3 BOD/2 m height = 4.8 kg BOD/$m^3 \times$ d

At such a high organic load, a removal rate of only 60% BOD may be expected. The simple calculation shows that wastewater would have to be recycled nearly five times to get the expected treatment quality and self-flushing effect. However, the trickling filter could be operated with lower hydraulic-loading rates if regular flushing is done.

The self-flushing (high-rate) trickling filter is a reliable system, despite fluctuations in the flow of wastewater. Nonetheless – as it requires a rotating sprinkler and pump for operation – the system is not a suitable DEWATS solution.

Starting phase, maintenance and calculating of dimensions

Details for calculation and instructions for operation are not included in this handbook as the trickling filter cannot be built and operated under DEWATS conditions.

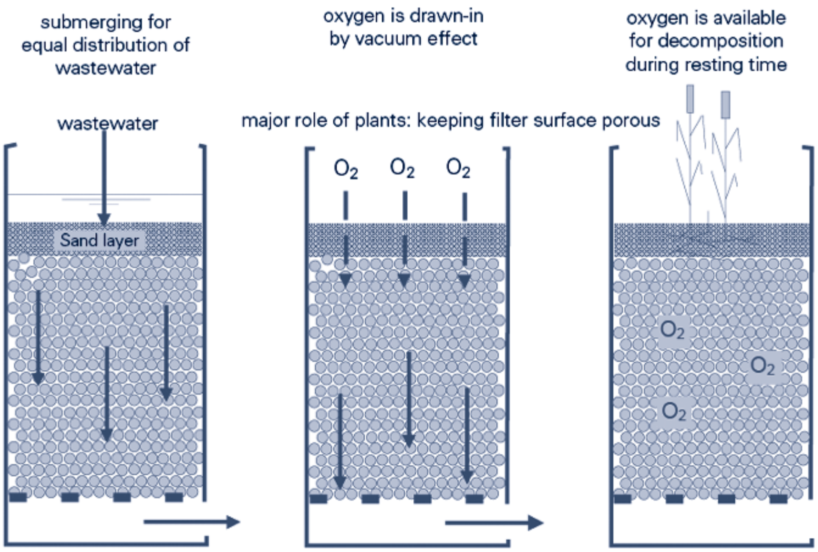
9.3.4 Constructed wetlands: horizontal gravel filter

Three basic-treatment systems are referred to as constructed wetlands:

- overland-treatment systems
- vertical-flow filters and
- horizontal-flow filters

In overland treatment the water is distributed on carefully contoured land by sprinklers. As the system requires permanent attendance and maintenance is not considered a component of DEWATS.

In vertical-filter treatment the wastewater is alternately distributed on two or three filter beds with the help of a dosing device (similar to the trickling filter). Treatment functions, predominantly, aerobically. Although vertical filters require only about half the area of their horizontal counterparts and often achieve higher treatment efficiency, the constant operational control, need for a dosing device and strict adherence to charging intervals make vertical filters less suitable for DEWATS.



Picture 9_19:
The principle of the vertical filter

Horizontal filters comply with DEWATS criteria, as they are simple in principle and require almost no maintenance – if well-designed and constructed. Planted horizontal gravel filters – also referred to as subsurface flow wetlands (SSF) or root zone treatment plants – provide natural treatment for pre-settled wastewater of a maximum COD content of 500 mg/l. They are ideal, therefore, as tertiary treatment for wastewater, which has already undergone secondary treatment in units, such as baffled reactors, anaerobic filters or biogas digesters. They are also appropriate for treating pre-settled greywater directly.

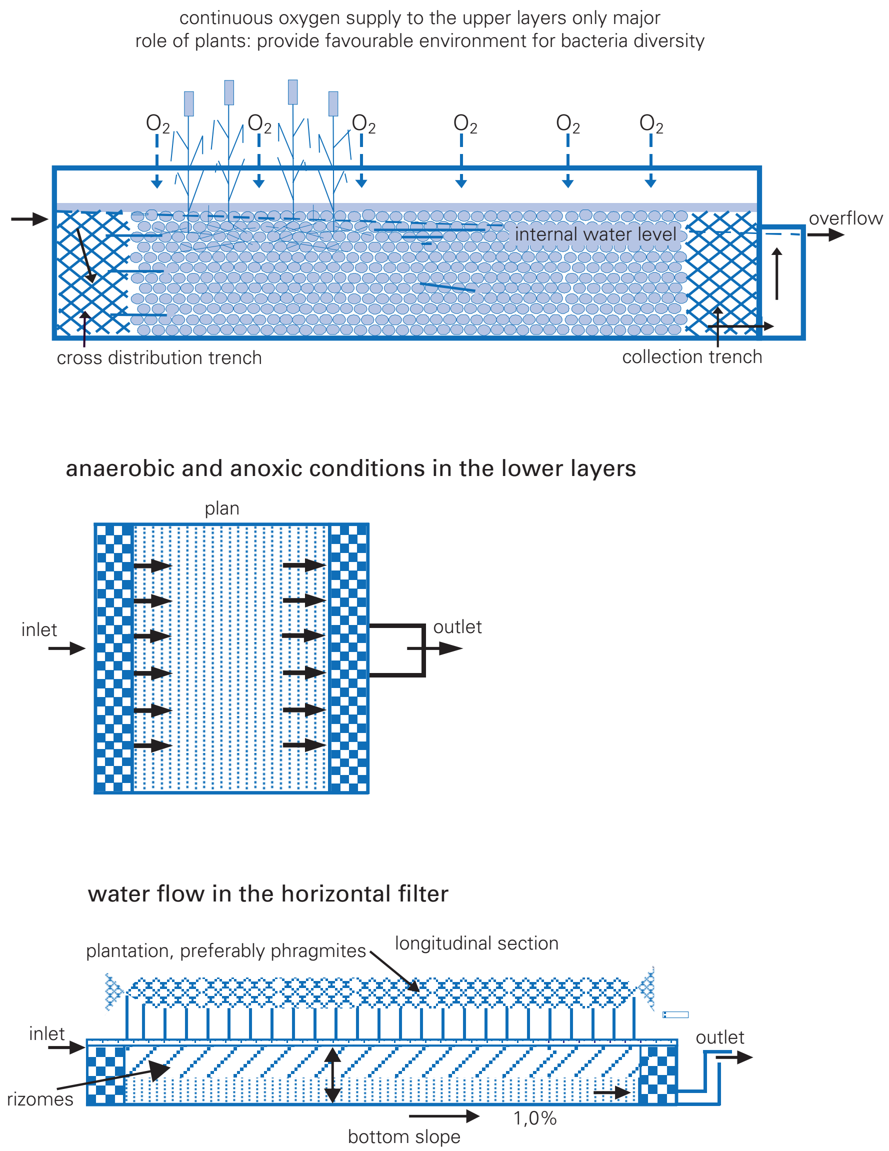
Although they don't look complicated – and are guite simple to operate, designing of sand and gravel filters requires a solid understanding of the treatment process and good knowledge of the filter medium that is to be used. Before deciding on filter treatment, one should therefore always consider the alternative of constructing wastewater ponds instead. Filter treatment, however, has the great advantage of keeping the wastewater below ground, thereby avoiding smell and insect breeding.

Since clogging is the biggest problem with horizontal ground filters, the wastewater must be pre-treated so that suspended solids are removed before it enters the treatment unit. When testing wastewater, after 60 minutes in an Imhoff cone the sediment should not be more than 1 ml/l, and not more than 100mg SS/l for non-settling industrial wastewater. If the COD-value of settleable solids is less than 40% of the total SS-value, then many of the solids are likely to be fat in colloidal form, which can reduce the hydraulic conductivity of the filter considerably (as may be the case with dairy wastewater).

The treatment process in horizontal ground filters is complex and not yet fully understood. Unlike the vertical filter, the horizontal filter (Picture 9_20) is permanently soaked with water and operates partly aerobic (free oxygen present), partly anoxic (no free oxygen but nitrate – NO_3 – present) and partly anaerobic (no free oxygen and no nitrate present). Combined with physical-filtration processes and the influence of plantation on the biological-treatment process and oxygen intake, the interaction of the separate treatment processes is difficult to predict.There are sophisticated methods for calculating the proper dimensions and treatment characteristics of different filter media, especially in relation to their hydraulic properties. However, such calculations make sense only if the required parameters are known, which is hardly ever the case. Rules of thumb, intelligently chosen, are more than sufficient for smaller-sized DEWATS plants. Going beyond these experience-based figures is not advisable without previous tests.

The rules of safe design are:

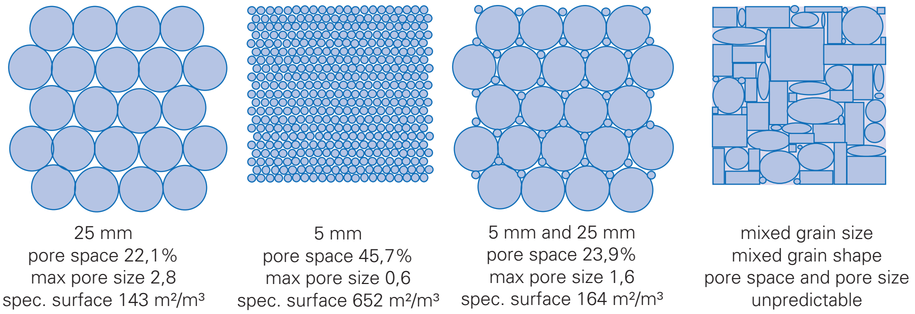
- large and shallow filter-bed
- wide inlet zone
- reliable distribution of inflow over the full width of the inlet zone
- round, coarse gravel that is nearly the same size as the filter medium



Picture 9_20:
The principle of the horizontal filter

Clogging is caused by suspended solids and by biological or mineralised sludge newly formed from the decomposition of organic matter. While large grain sizes with a high percentage of voids prevent clogging, they also reduce treatment performance. In order to utilise the full filter, the front part of the bed must have voids that are small enough to retain some of the SS, while being large enough to allow further SS removal in later parts of the bed. Round, uniform gravel of 6 - 12 mm or 8 - 16 mm is best.

The use of broken-edged stones reduces conductivity by approximately 50% compared to round gravel, due to turbulent flow within irregular pores. So large grains should be chosen when applying flat or mixed grain shapes, such as chippings from broken stones. In the case of mixed grain size, it is advisable to screen the gravel with the help of a coarse sieve: use the larger grains in the front and the smaller grains in the later sections of the filter. Care must be taken when changing from a larger to a smaller grain size because blockages mostly happen at the point of change.



Picture 9_21: Influence of grain size and shape on filter properties

A rather flat slope ($\alpha < 45°$) should join one grain size to the other to ensure a larger connecting area. In particularly when grain diameters differ considerably, an intermediate zone consisting of intermediate size may be useful. Mixed-grain sizes do not improve hydraulic conductivity. Removing fine soil from gravel by washing is more important than ensuring the exact grain size.

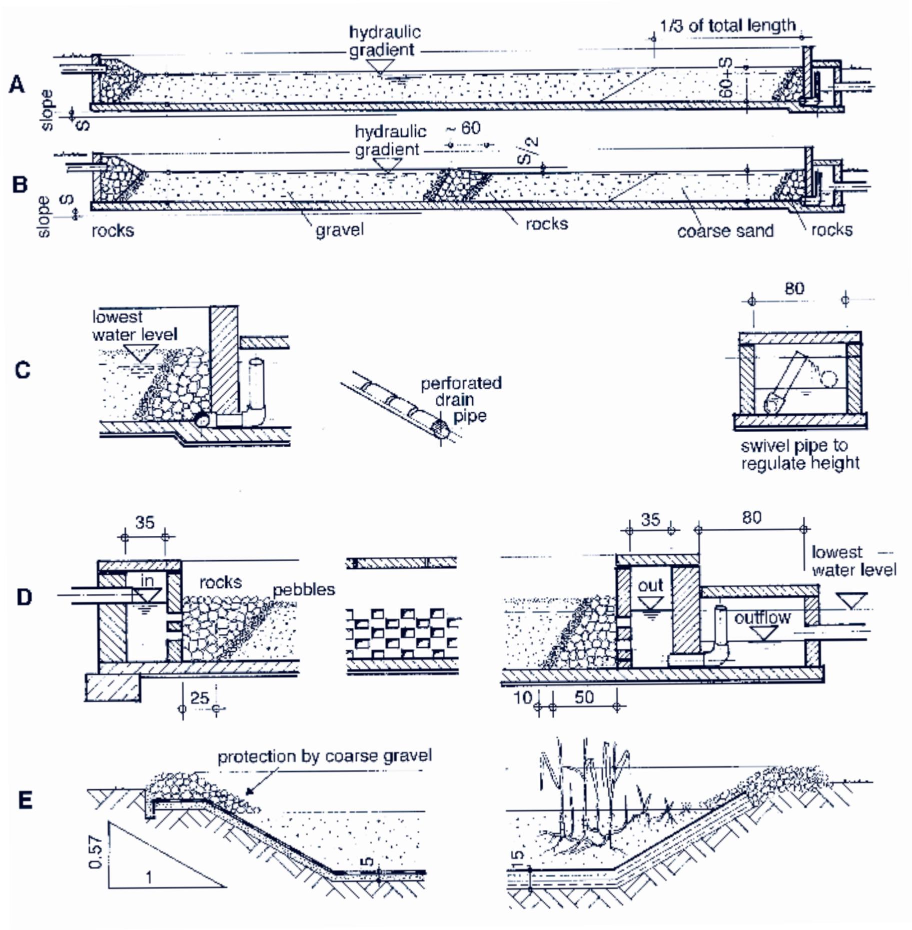
If the length of the filter-bed is more than 10 m, an intermediate channel for re-distributig cross-flow should be provided. The distribution channel can also serve as a terrace step in the case of steeply sloping topography (Picture 9_23).

The relation between organic load and oxygen supply reduces with length. This happens because oxygen is supplied evenly over the total surface area, whereas the organic load diminishes during treatment. It is most likely, therefore, that anaerobic conditions prevail in the front part, while aerobic conditions reach to a greater depth in the rear part. However, only the upper 5 to 15 cm can really be considered an aerobic zone.

A clogged gravel filter can become useful again if it is not used for periods of several months, because of a process called autolysis; when forced to live without feed, the bacteria live on their own bacterial mass.

Picture 9_22
Horizontal gravel filter in India

Filter clogging normally results in surface flow of wastewater. This is usually not desired, although it hardly reduces the treatment efficiency if flow on the surface maintains the assumed retention time inside the filter (this could be the case with dense plant coverage). When filters are well-protected and a long way from residential areas, there is no harm in letting some of the wastewater run above the horizontal surface. Such "overland treatment" produces very good results – especially when the water is equally distributed and does not fester in trenches.



Picture 9_23: Horizontal gravel filter (subsurface flow filter). A: Filter basin in masonry and concrete structure, finer gravel is used in the rear portion. B: Long filter bed with additional distribution trench in the middle; the trench is filled with rocks and allows a step in the surface level. C: Detail of collection pipe and swivel arm at the outlet side. D: Details of inlet and outlet structure for improved distribution of flow for wider filter beds. E: Details of filter basins using foils or clay packing for sealing. Sloped side walls are less costly, but plants will not grow near the rim

Knowledge of the amount of void space within the filter material is essential for calculating the retention time and planning the treatment process. Gravel has 30 to 45% voids, depending on size and shape. (The calculation of HRT in the spreadsheet in table 30 is based on 35% void space; it can be adapted propor– tional, if the actual void space is greater.) Void space can easily be determined by measuring the water that can be added to a bucket full of gravel (Picture 9_24).

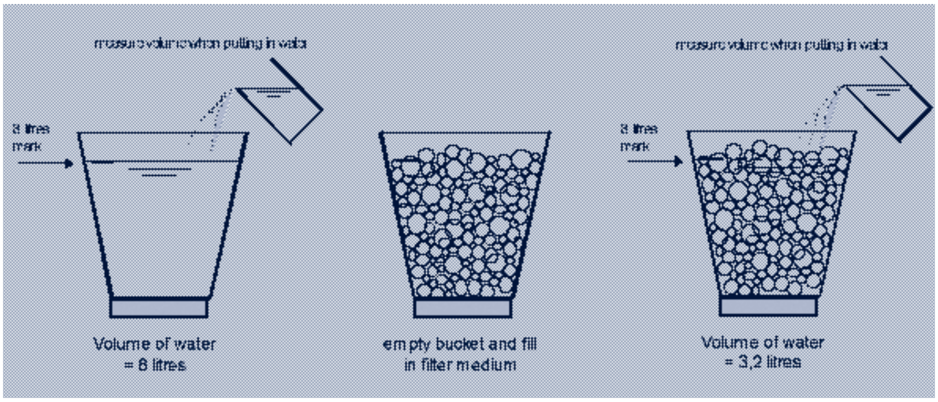
Table 20: Theoretical properties of gravel and sand as filter material: lower values should be applied for wastewater when designing filter beds

filter medium	diameter of grain mm	pore volume		theoretical conductivity	
		coarse	total	m/s	m/d
gravel	4 - 40	30%	35% - 40%	4.14E - 03	350
sand	0.1 - 4	15%	42%	4.14E - 04	35

For high conductivity, large pore size is more important than total pore volume. Pre-wetted gravel shall be used when the pore volume is tested, ensuring that pores of only capillary size are "closed" in advance.

In reality, short cuts and volume-reduced by partly clogged areas result in 25% shorter retention times and, consequently, inferior performance[31]. For this reason, the filter-bed should not be deeper than the depth to which plant roots can grow (30 - 60 cm), as water will tend to flow faster below the dense cushion of roots. However, treatment performance is generally best in the upper 15 cm because of oxygen diffusion from the surface. Shallow filters are more effective, therefore, than deeper beds of the same volume.

31 See: Shilton et all, 1996



Picture 9_24: Determining pore space of filter medium on site. Example: the empty bucket is full after pouring 8 litre of water. The bucket filled with gravel absorbs 3.2 litre of water: Voids space is 3.2/8 = 0.40 or 40%

Uniform distribution of wastewater throughout the filter requires an equally distributed supply of water at the inlet – and equally distributed reception at the outlet side. Trenches filled with rocks 50 to 100 mm in diameter are provided at both ends to serve this purpose. A perforated pipe, which is connected to the outlet pipe, lies below the strip of rocks that form the collection trench. The height of the outlet can be adjusted by a swivel arm, fixed to a flexible elbow. By lifting it until water appears at the surface of the filter near the inlet, the water level in the filter can be adjusted according to hydraulic conductivity. While the top of the filter is kept strictly horizontal to prevent erosion, the bottom slopes down from inlet to outlet ideally at 1%. Site conditions permitting, bigger slope is also possible. To prevent erosion, long filters should have a terraced surface rather than a slope (see picture 9_23 (B)).

The percolation of wastewater into the ground is not desirable so the bottom of the filter must be sealed. While solid-clay packing might be sufficient, heavy plastic foils are more common. A concrete basin with straight, vertical masonry walls allows plants to grow up to the outer rim – not possible with the smooth embankment that plastic foils would require (see picture 9_23 (E)).

In a dry climate, trees search for water and their roots may break the walls and grow into the filter. Whenever possible, trees should not be planted directly beside the filter; this will avoid the structural problems caused by the roots and the unwanted sealing of the filter surface by fallen leaves.

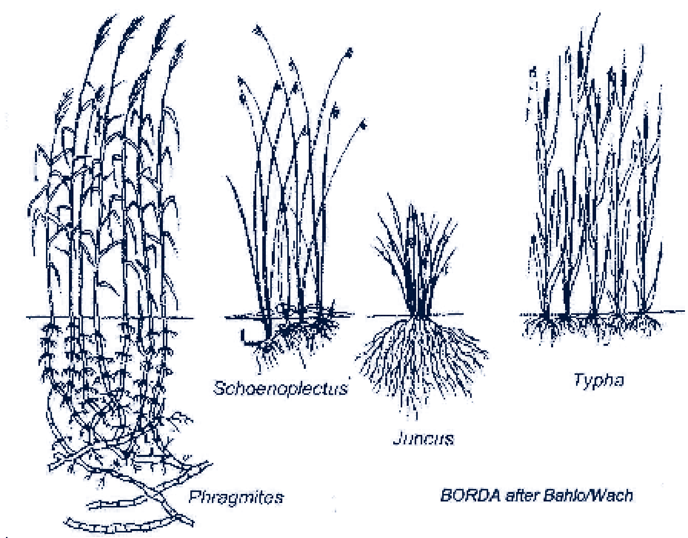
Observation in Europe indicates that the performance of gravel filters diminishes after several years. How long a horizontal filter functions properly depends on several factors: grain size and shape of gravel, the nature and amount of suspended solids in the wastewater, and the temperature and the average loading rate.

If the filter is drained during resting time, alternate charging can increase the treatment performance of horizontal filters. To allow alternate feeding, the total filter area should be divided into several compartments or beds. Other reports recommend that the filter is changed every eight to 15 years. This timeframe is only a rough estimation and – as stated above – depends on the loading rate and structural details, the impact of which is almost impossible to predict in practice. Weaker wastewater, lower loading rates and larger gravel size generally increase the lifetime of the system.

Ground filters are covered by suitable plantation – any type of hydro-botanical plant that will grow on wastewater and has deep–reaching and widely spreading roots. The choice of plant influences treatment efficiency; some scientists claim that the micro-environment created inside the filter is responsible for equilibrium between sludge production and sludge "consumption". Such equilibrium is only likely with low loading rates.

The plants are not normally harvested. *Phragmites australis* (reeds), found almost anywhere, are considered to be ideal because their roots form horizontal rhizomes that guarantee a perfect root-zone filter bed (see picture 9_25). Most swamp and water grasses are also suitable, but not all of them have extending or deep-enough roots. Depending on the type of wastewater, different plants might be preferable: *Typha angustifolia* (cat-tails), together with *Scirpus lacustris* (bull rush), have been to be found the most suitable plants for wastewater from petrol refineries, while the large, red- or orange-flowering iris (sometimes known as "mosquito lily") is a beautiful plant, which grows well on wastewater but is only suitable for shallow, domestic gravel beds. Forest trees have also been used and are deemed to be only slightly less efficient[32]. At least two clumps of plants or four sprouted rhizomes should be placed per square metre when planting is started.

32 Kadlec et all, 1996



Picture 9_25: Plant species common for gravelfilter plantation

Within a horizontal filter, plants seem to be "catalysts" rather than "actors" Plants transport oxygen via their roots into the ground. Some scientists claim that this process also supplies surplus oxygen, thereby creating an aerobic environment, while others have shown that plants only transfer as much oxygen as they need to fulfil their own nutrient requirements. For example, Brix and Schierup claim that plants provide 0.02 g $O_2/m^2 \times d$ to the filter bed, while consuming 2.06 g $O_2/m^2 \times d$ for themselves. Nonetheless, it is assumed that toxic substances near the roots are eliminated by oxidation. The complex ecosystem that exists in planted gravel filters produces good and reliable treatment results, in part, which must be due to aerobic treatment. This is underlined by reports which claim that COD reduction rates of over 95% can be achieved – which would not be possible under anaerobic conditions alone. The uptake of nutrients by plants is of relatively little importance, especially when plants are not harvested.

Starting phase and maintenance

Young plant seedlings may not grow on wastewater. So is advisable to start feeding the plant with plenty of fresh water and to let the pollution load grow parallel to plant growth.

When plants are under full load, the outlet level is adjusted according to flow. Water should not stand on the surface near the inlet. If this happens, the swivel arm at the outlet should be lowered. Optimal water distribution at the inlet side is important and must be controlled from time to time. Replacement of the filter media might be necessary when treatment efficiency declines. Since there is no treatment during the time that the filter media is being replaced, it is advantageous to install several, parallel filter-beds.

To prevent clogging of the filter with fine soil, stormwater should neither be mixed with the wastewater before the treatment step, nor should outside stormwater be allowed to overflow the filter bed. Erosion trenches around the filter-bed should always be kept in proper functioning condition.

Calculating dimensions

If percolation properties – the so called hydraulic conductivity of the filter body – is known, then the required cross-sectional area at the inlet can be calculated using Darcy's Law. To compensate for reduced conductivity with use, only a fraction of the calculated figure for clear water should be used for designing the plant. The conductivity applied in the spreadsheet takes this into consideration. It does not, however, take head of pessimistic statements, which claim that only 4% of the clear-water conductivity should be used.

Darcy's Law

$$A_c = \frac{Qs}{kf \times dH / ds}$$

$$\text{cross-section area of filter-bed (m)} = \frac{\text{flow rate (m/sec)}}{\text{hydraulic conductivity (m/sec) x slope (m height/m length)}}$$

Picture 9_26: Darcy's law for calculation of hydraulic conductivity

Picture 9_27: Horizontal Gravel Filter during construction. Constructed above ground

9.3.5 Vertical sand filter

Although the vertical filter is – compared to the horizontal filter – the more efficient and more reliable treatment system from a technical and scientific point of view, it is not suitable for DEWATS because of its permanent operational control, necessity of a dosing device, and strict adherence to charging intervals. Nonetheless, the following section introduces this system to provide a better understanding of related treatment processes.

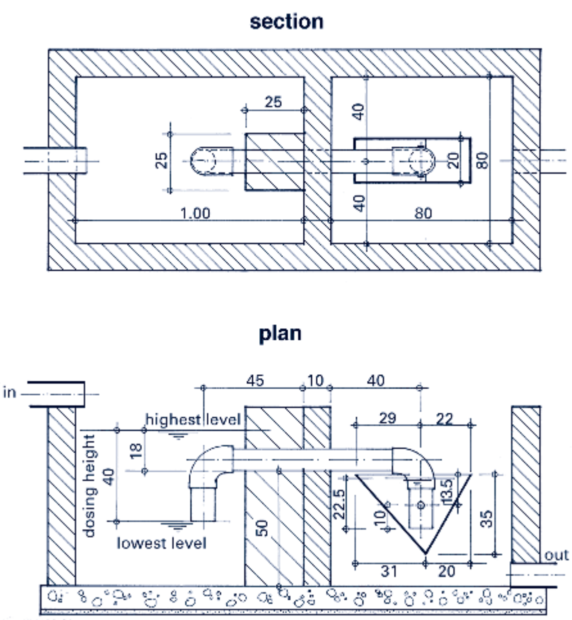
The vertical filter functions in a similar way to an aerobic trickling filter and, consequently, must be fed at intervals with defined resting times between dosing charges. In addition to the short intervals, which are regulated by dosing devices, longer resting periods of one to two weeks are required. This is only possible if there are at least two alternately fed filter beds.

Feeding in doses is necessary for equal water distribution. The resting times are needed so that oxygen can enter the filter after wastewater has percolated (see picture 9_19 on page 201). Doses must be large enough to temporarily flood the complete filter and to distribute the water evenly over the surface, but small enough to allow enough time for oxygen to enter before the next flooding. The filter material, therefore, must be fine enough to cause flooding and porous enough to allow quick percolation. During the short charging times, the wastewater is exposed to the open, which can create bad odour in the case of anaerobic pretreatment.

The body of the vertical filter consist of a fine top layer, a medium middle layer and a rough bottom layer. The area below the filter media is a free-flow area, connected to a drainpipe. The free-flow area is also connected to the open via additional vent pipes. The fine top layer guarantees homogeneous flow distribution; the middle layer is the actual treatment zone, while the bottom layer is responsible for providing wide-open pores to reduce the capillary forces, which would otherwise decrease the effective hydraulic gradient.

Vertical filters are normally 1 m to 1.20 m in deep. However, if there is enough natural slope and good ventilation, vertical filters can be constructed up to three metres high. Vertical filters may or may not be covered by plantation. In the absence of plantation, the surface must be scratched at the beginning of each resting period, in order to allow enough oxygen to enter; with dense plantation, the stems of the plants ensure sufficient open pores in the filter surface.

Dosing of flow can be regulated with self-acting siphons, automatic controlled pumps or tipping-buckets. The latter is most suitable under DEWATS conditions because its dertermining principle is easily understood and the hardware can be manufactured locally.



Picture 9_28:
Dosing chamber with tipping bucket for the controlled operation of a siphon. The bucket closes the siphon until it is filled with water. When losing its equilibrium due to the weight of the water, the bucket turns over and opens the siphon. It falls back into horizontal position to receive new water, which again closes the siphon for the next flush

Flooding is the only reliable method of achieving equal distribution of water over the entire filter; charging points spaced across the surface area allow quick submergence. It is not possible to achieve equal distribution by designing supply pipes of different diameters and length, leading to various outlet points. This has been tried often enough; we don't need new failures. Flush distribution is a must.

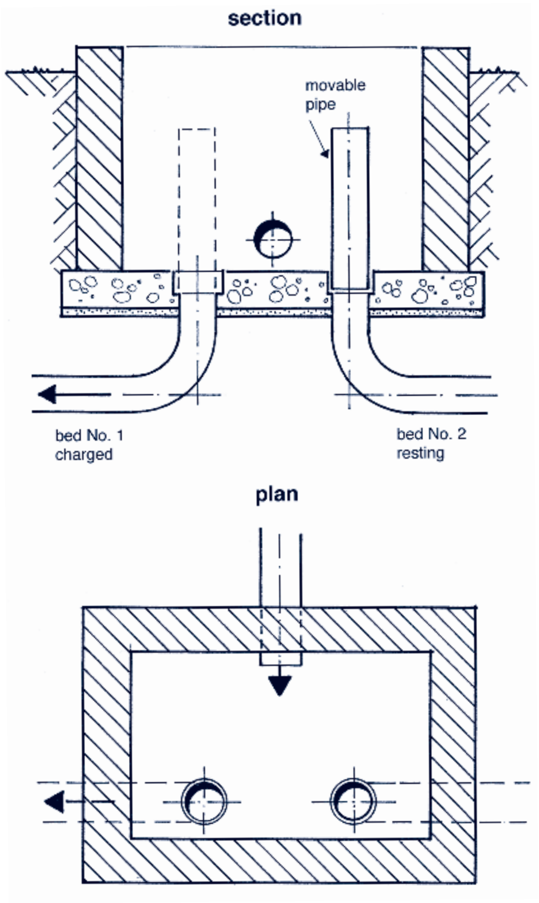
The flow to each bed can be prevented with a valve within the inlet pipe. Alternatively, the valve can be replaced by a straight standing piece of pipe in the dosing chamber.

While vertical filters can bear a hydraulic load up to 100 $l/m^2 \times d$ (100 mm/m^2 = 0.1 m), it is better to restrict loading to 50 $l/m^2 \times d$. The organic load may reach up to 20g $BOD/m^3 \times d$; in the case of re-circulation, 40g $BOD/m^2 \times d$ is possible (M&E). In the case of pre-treated domestic wastewater, the hydraulic load is the deciding factor. Some engineers use these values only for active filter-beds, while others claim that the resting beds must be included within the calculation. If there is any doubt, testing is recommended. However, larger filter areas are always preferable.

Permeability can be calculated with Darcy's Law (on page 211), whereas $dH/ds = 1$. The flow speed ($v = Qs/Ac$), therefore, is equal to the hydraulic conductivity (k).

Starting phase, maintenance and calculating dimensions

The vertical sand filter does not belong to DEWATS. Detailed operational instructions have been deliberately excluded from this handbook to ensure readers don't get the impression that the vertical filter can be constructed and operated under DEWATS conditions.



Picture 9_29:
Distribution chamber for alternate feeding of filter beds. A piece of straight pipe is placed on the outlet, which is to be temporarily closed

9.4 Ponds

Ponds (lagoons) are artificial lakes. They provide wastewater treatment though processes, that are also found in nature. Different treatment processes can be utilised; depending on the design of the artificial lake, series of ponds can be used to combine different treatment effects.

Ponds are ideal DEWATS and should be given preference over other systems whenever land is available. Ponds are to be preferable over underground gravel filters, if sympathetic to the surroundings; facultative or anaerobic ponds must be far enough from human settlements to avoid nuisance caused by bad odours or mosquito breeding. Polishing ponds can be closer, if fish are held within the water body; fish that belong to *gambusia spp.* are commonly used for mosquito control in tropical countries.

Pure pond systems are cheap and need almost no maintenance, even if large.

Ponds may be classified into:
- sedimentation ponds (pre-treatment ponds with anaerobic sludge stabilisation)
- anaerobic ponds (anaerobic stabilisation ponds)
- oxidation ponds (aerobic cum facultative stabilisation ponds)
- polishing ponds (post-treatment ponds, placed after stabilisation ponds)

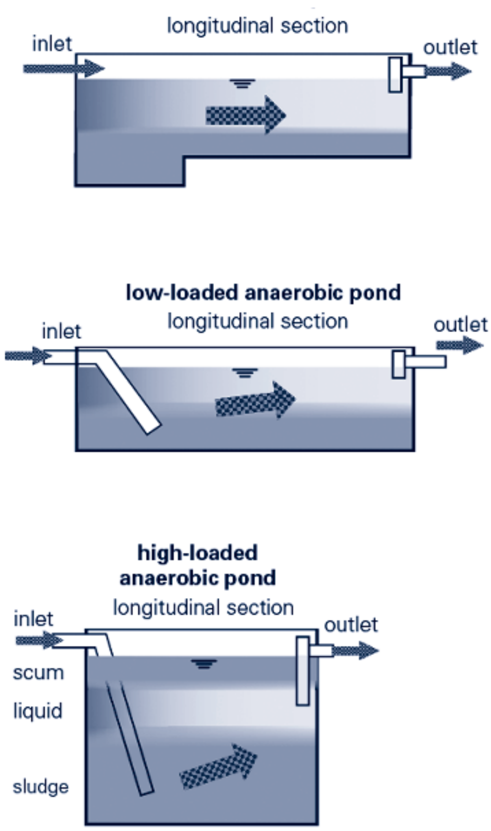
Pond systems intended to provide full treatment normally consist of several ponds serving different purposes. For example, a deep anaerobic sedimentation pond for sedimentation cum anaerobic stabilisation of sludge, two or three shallow aerobic and facultative oxidation ponds with longer retention times for predominantly aerobic degradation of suspended and dissolved matter, and one or several shallow polishing ponds for the final sedimentation of suspended stabilised solids and bacterial mass. Wastewater ponds for fish farming require low organic loading and, in addition, should be diluted by four to five times the amount of river water. Otherwise, the pond must be about 10 times larger than calculated in the spreadsheet (see Table 23).

Artificially aerated ponds are not considered to be DEWATS and, therefore, are not dealt with in this handbook. It may be enough to know that such ponds are 1.5 to 3.5 m deep, usually work with a five days hydraulic retention time (HRT) and organic loads of 20 to 30 g BOD/$m^3 \times d$. The energy requirement for aeration is about 1 - 3 W/m³ of pond volume. Wherethere is only a little scum only the surface of anaerobic ponds may be aerated to reduce the foul smell.

9.4.1 Anaerobic ponds

Anaerobic ponds are deep (2 to 6 m) and highly loaded (0.1 to 1 kg BOD/m³×d). Anaerobic conditions are guaranteed by the depth of the pond, thereby requiring less surface area than aerobic-facultative oxidation ponds.

It is possible to provide separate sludge-settling tanks before the main pond, in order to reduce the organic-sludge load. Such settling tanks should have a HRT of less than one day, with the exact HRT depending on the kind of wastewater.



Picture 9_30: Principles of anaerobic ponds. Sedimentation ponds have a HRT of about one day, ponds with low loading are supposed to be odourless because of almost neutral pH, highly loaded ponds form a sealing scum layer on top

Anaerobic ponds with an organic loading rate of below 300 g/m³×d BOD are likely to remain at an almost neutral pH. Consequently, they release little H_2S and, therefore, are almost free from an unpleasant smell. Highly loaded anaerobic ponds omit foul odour, until a heavy layer of scum has been developed. Before this layer exists, the upper region of the pond will remain aerobic; these ponds are called facultative-anaerobic.

Depending on the properties of the wastewater, the desired treatment effect and possible post-treatment, anaerobic ponds are designed for hydraulic retention times of between one and 30 days. The HRT determines whether only settled sludge or all of the liquid is treated. For domestic wastewater the anaerobic pond may function as an open septic tank. It should be small, in order to develop a sealing scum layer; in this case, treatment efficiency is only in the range of 50 to 70% BOD removal.

"Wrong" retention times result in stinky effluent. If the retention time is longer than one day, not only bottom sludge but also the liquid portion begins to ferment. On the other hand, if the retention time is too short for the liquid to stabilisate substantially, the effluent remains at a low pH and stinks of H_2S. Too-short retention times have the same effect as too-high organic loading rates.

pollutant	dimension	inflow	outflow	removal rate
suspended solids	mg/l	431	139	68%
COD mg/l	mg/l	1189*	505	58%
BOD_5	mg/l	374	190	49%
Nkjel	mg N/l	116	99	15%
P total	mg/l	26	24.5	6%
fecal coli	No/100 ml	6,156,000	496,000	92%
fecal strepto	No/100 ml	20,900,000	1,603,000	92%
nematode ova	No	139	32	77%
cestode ova	No	75	18	76%
helminth ova	No	214	47	78%
*the high COD/BOD ratio is caused by mineral of pollution which is also the reason for the COD-removal rate being higher than that of the BOD_5				

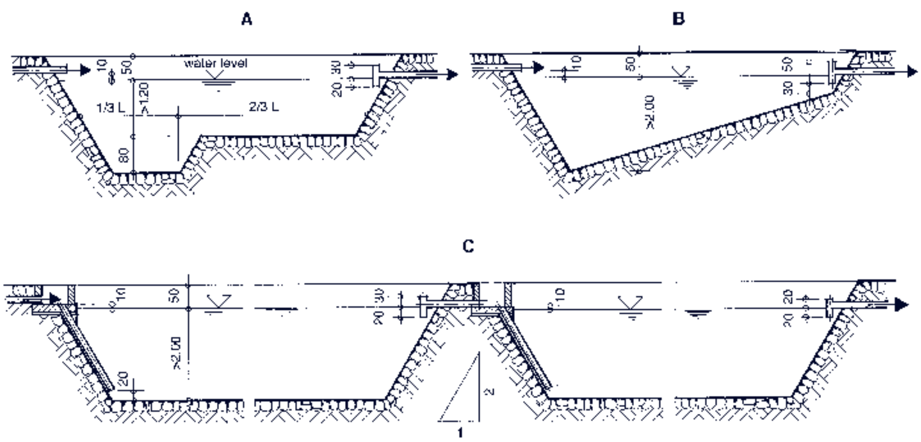
Table 21:
An example of the high performance of a simple settling pond
Source: Drioache et all, 1997

In industries, such as sugar plants or distilleries, anaerobic ponds are often used as the first treatment unit, followed by oxidation ponds. The treatment efficiency of high-loaded ponds with long retention times ranges from 70 to 95% BOD removal (CODrem. 65 to 90%), depending on the biodegradability of the wastewater. Several ponds in series are recommended for long retention times.

Anaerobic ponds are not very efficient in treating wastewater with a wide COD/BOD ratio (> 3:1). For this type of wastewater, sedimentation ponds with very short retention times, followed by aerobic/facultative stabilisation ponds are recommended.

ambient temperature °C	org. load BOD g/m³*d	efficiency BOD rem. %
10	100	40
15	200	50
20	300	60
23	330	66
25	350	70
28	380	70
30	400	70
33	430	70

Table 22:
Design parameters for low-loaded anaerobic ponds in relation to ambient temperature
Source: Mara 1997



Picture 9_31:
Cross-sections of anaerobic ponds constructed from rocks, with cement-mortar pointing.
A and B: A deeper inlet section accumulates most of the sludge within a limited surface area.
C: Two anaerobic ponds in series. The first pond may be highly loaded (scum sealed), while the second pond may be low loaded (neutral pH)

Pond size is also determined by the long-term sludge-storage volume. Anaerobic ponds with sufficient, integrated sludge storage make sludge-removal intervals of over 10 years possible.

Starting phase and maintenance

Start-up does not require any special arrangements. But one must be aware of the fact that a heavily loaded pond will release bad odour until a layer of scum seals the surface. Inlet and outlet structures should be monitored during operation. A drop in the effluent quality is a warning that the sludge must be removed. If this is neglected, the receiving waters or the ensuing treatment units will suffer the consequences.

Calculating dimensions

Retention time and volumetric organic load are the two design parameters for anaerobic ponds. A non-smelling pond loaded with 300 g BOD/$m^3 \times d$, for a short HRT of one day, requires approximately 0.2 m^3 per capita for domestic wastewater. Anaerobic stabilisation of the liquid fraction requires longer retention times, the calculation of which depends on temperature, desired treatment quality and organic load. The organic loading rate should not exceed 1 kg BOD/$m^3 \times d$. For exact calculation please refer to the formula in the spreadsheet (Table 22).

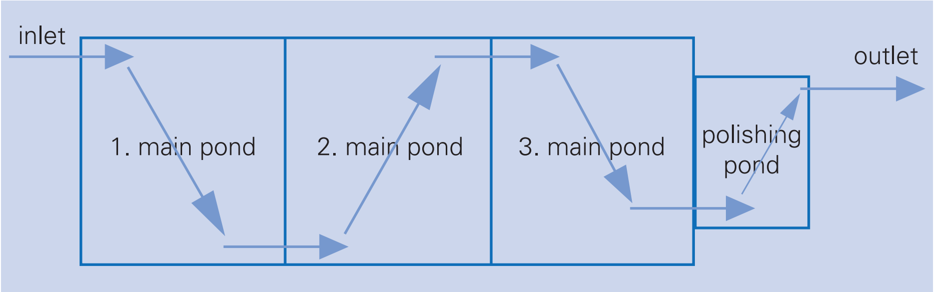
Picture 9_32: Polishing Pond in India

9.4.2 Aerobic ponds

Aerobic ponds receive most of their oxygen via the water surface. For loading rates below 4 g BOD/m²×d, surface oxygen can meet the full oxygen demand. Oxygen intake increases at lower temperatures and with surface turbulence caused by wind and rain. Oxygen intake also depends on the actual oxygen deficit up to saturation point so may vary at 20°C between 40 g O_2 /m²×d for fully anaerobic conditions and 10 g O_2 /m²×d in the case of 75% oxygen saturation.[33] (Mudrak&Kunst, after Ottmann 1977).

33 See Mudrake et all, 1997

The secondary source of oxygen comes from algae via photosynthesis. However, in general, overly intensive growth of algae and highly turbid water prevents sunlight from reaching the lower strata of the pond. Oxygen "production" is then reduced because photosynthesis cannot take place. The result is a foul smell because anaerobic facultative conditions prevail. Algae are important and positive for the treatment process, but are a negative factor when it comes to effluent quality. Consequently, algae growth is allowed and wanted in the beginning of treatment, but not desired when it comes to the point of discharge because algae increase the BOD of the effluent. Algae in the effluent can be reduced by a small final pond with a maximum one-day retention time. Larger pond areas – low loading rates with reduced nutrient supply for algae - are the most secure, but also the most expensive measure.

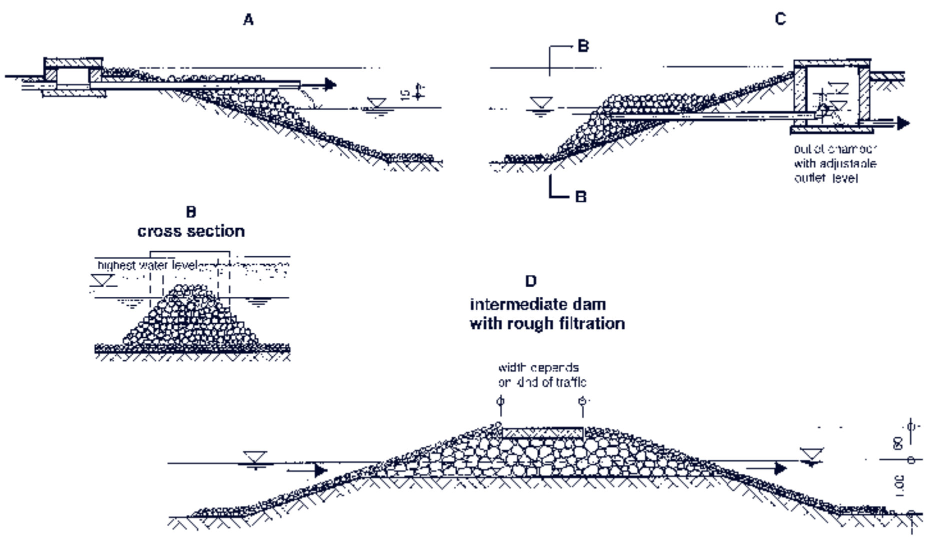


Picture 9_33: Flow pattern of aerobic-facultative ponds in series

The laboratory results of effluent wastewater often give a false impression of insufficient treatment. As nearly 90% of the effluent BOD comes from algae, many countries allow higher BOD loads in the effluent from ponds, as compared to other treatment systems. Baffles or rock bedding before the outlet of each of the ponds have a effect of algae retention. Intelligent structural details increase the treatment quality considerably at hardly any additional cost – and may be seen as being as important as adequate pond size.

Treatment efficiency increases with longer retention times. The number of ponds is of only relative influence. With the same total surface, splitting one pond into two ponds increases efficiency by approximately 10%. Having three instead of two ponds adds about 4% and from three to four ponds having inreases efficiency by another 2%.

This shows that having more than three ponds is not justifiable from an economic point of view because the same effect can be achieved by just enlarging the surface area. Instead of constructing the dams and banks of an additional pond, the required land should be used as additional water area.

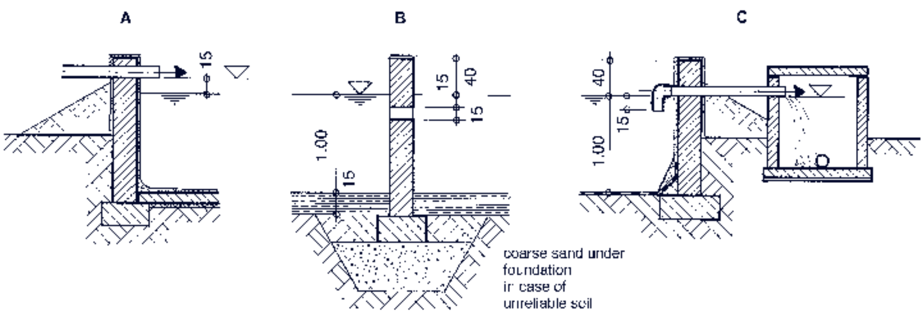


Picture 9_34: Section through a large aerobic-facultative stabilisation pond. Banks should be protected against erosion by waves. A: Inlet; banks should also be protected against erosion by influent. B: Cross-section B-B (front view of C). C: Outlet structure with swivel arm to adjust height of pond according to seasonal fluctuation of water volume.

The first pond may be as much as twice the size of the others, if there are several inlet points. In principle, having a several inlet points – to distribute the pollution load more equally and to create a larger area for sedimentation – is an advantage. On the other hand, it might be advisable to provide a slightly separated inlet zone in order to avoid bulky, floating matter, littering the total pond surface.

The inlet points should be as far away from the outlet as possible. The outlet should be below the water surface to retain floating solids, including algae. Gravel beds acting as roughing filters are advisable between ponds in series and before the final outlet.

The erosion of banks by waves could be a problem with larger ponds. Therefore, the slope should be 1 (vertical) to 3 (horizontal) and covered with rocks or large bits of gravel. Banks and dams can be protected by planting macrophytes, such as cat-tail, or phragmites. Dams between ponds should be paved and wide enough to facilitate maintenance.



Picture 9_35:
Details of aerobic-stabilisation ponds (basins) of smaller size. A: Inlet structure, concrete flooring, B: Partition wall, compacted clay flooring, C: Outlet structure, foil flooring (protection against misuse may be advisable)

Fish feed on algae; however, fish can only live if there is enough dissolved oxygen available – 3 mg/l is the absolute minimum for sludge fish. Therefore, the dilution of wastewater with other sources (rivers, existing lakes) is necessary to allow fish farming; alternatively, only very-low organic-loading rates are permissible.

Aerobic stabilisation ponds must be shallow enough to permit adequate oxygen intake but deep enough to prevent weed growth at the bottom of the pond. A depth of 90 cm to 1 m in a warm climate and up to 1.2 m in cold-climate zones (due to frost) is suitable. Deeper ponds become facultative or even anaerobic in the lower strata.

Smaller volumes of wastewater, such as from schools, hospitals or residential houses are better pre-treated in Imhoff tanks, septic tanks, baffled reactors or, at the least, sedimentation pits, before reaching the aerobic stabilisation pond. Properly operated Imhoff tanks, which have odourless effluent are preferable. A septic tank with smelly effluent is to be preferred if regular desludging of the Imhoff tank cannot be guaranteed. If pre-treatment is not provided, the pond must have a deeper sedimentation zone near the inlet; bad odour is to be expected. It might be wiser, therefore, to construct a small sedimentation pond, on which a sealing scum layer will develop. Should the scum layer reach a thickness of more than 10 cm, papyrus can be grown on it to make it look more attractive.

Starting phase and maintenance

The pond matures much faster if it is filled with river water *before* the first wastewater enters. With the exception of controlling the inlet and outlet structures regulary, no permanent attendance is required. But the performance of the pond should be monitored and any disturbance of the water quality should be investigated to find the cause. Sludge must be removed at defined intervals, to avoid a decline in treatment quality. Adequate sludge removal, handling and treatment is discussed in detail in chapter 14.

Calculating dimensions

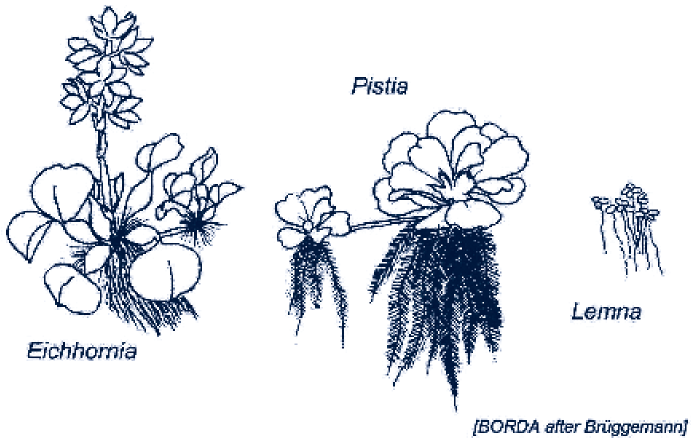
Organic surface load and hydraulic retention time are the two decisive design parameters. While the minimum hydraulic retention time ranges from 5 to 20 days, the maximum organic load depends on the ambient temperature (see Table 23 on this page). The amount of sunshine hours is import, as UV radiation is effective at destroying pathogens. Although this consideration is not included in the calculation, ponds should be slightly oversized in areas with permanent cloud cover. Organic loading should be less than 20 g BOD/m²×d. For domestic wastewater, a pond surface of between 2.5 and 10 m² may be estimated per capita. All values depend on the type of pre-treatment, the surrounding temperature, and health objectives. For more exact calculation, please refer to the formula applied in the computer spreadsheet (see Table 23).

5 days HRT	
ambient temper. °C	org./load BOD g/m²*d
10	7.0
15	11.7
20	17.7
23	21.8
25	24.5
28	28.4
30	30.8
33	33.8

Table 23:
Organic surface loading for aerobic-facultative ponds
Source: Mara, 1997

9.5 Aquatic-plant systems

Water hyacinth, duckweed, water cabbage and other aquatic plants can improve the treatment capacity of pond systems. The heavy metals that accumulate in water hyacinths are removed when the plants are harvested. Duckweed is a good substitute for algae; if not confined within fixed frames, duckweed is blown by the wind to the lee-side of the pond. If it is retained in a surface baffle, it leaves a cleaner effluent. Improved treatment efficiency however, is only guaranteed by regular attendance and harvesting. Special design features for harvesting increase the total area requirement of the treatment system. The evaporation rate of aquatic-plant systems is four times higher than that of open ponds (in the range of 40 $l/m^2 \times d$ in hot climate).



Picture 9_36: Aquatic plants, commonly used for wastewater treatment

The area required for a pond is almost the same, regardless of aquatic plants. If the organic-loading rate is low, plants provide protect of mosquito-controlling fish from birds. However, some plants like water hyacinth are disad–vantageous, as they mosquito larva from fish and provide shelter for snakes. High organic loading rates – where additional treatment by aquatic plants is most beneficial – do not allow the survival of fish for mosquito control.

As aquatic-plant systems become a nuisance if they are not maintained properly, they are not considered as DEWATS. However, aquatic plants make sense if utilised in conjunction with wastewater farming for intensive and controlled nutrient recycling, or to improve the appearance of residential areas.

Starting phase and maintenance

Operation and maintenance is mainly an agricultural-management issue rather than a wastewater-treatment issue. The pond should start off with fresh, river water and the pollution load should be slowly increased, as plant cover increases. Plants must be harvested regularly to prevent bottom sludge forming from dead plants. Duckweed, in particular, should be kept within frames. Inlet and outlet structures should be controlled regularly.

Calculating dimensions

For practical reasons, please refer to the same formula as for unplanted oxidation ponds (see Table 23).

Picture 9_37: Wastewater-treatment pond at a hospital in Pondicherry, India

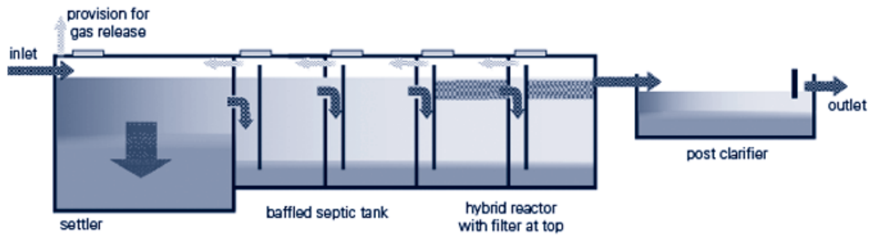
9.6 Hybrid and combined systems

Each technology has its strengths and weaknesses. It makes sense, therefore, to combine different treatment units into a more efficient treatment system. An example of such a combined system could be sedimentation in a settler or septic tank followed by anaerobic decomposition of non-settleable suspended solids in anaerobic filters or baffled septic tanks. Further treatment in ponds or ground filters provides aerobic conditions. Deciding which technologies are most appropriate for combining depends on by treatment requirements and boundary-site conditions.

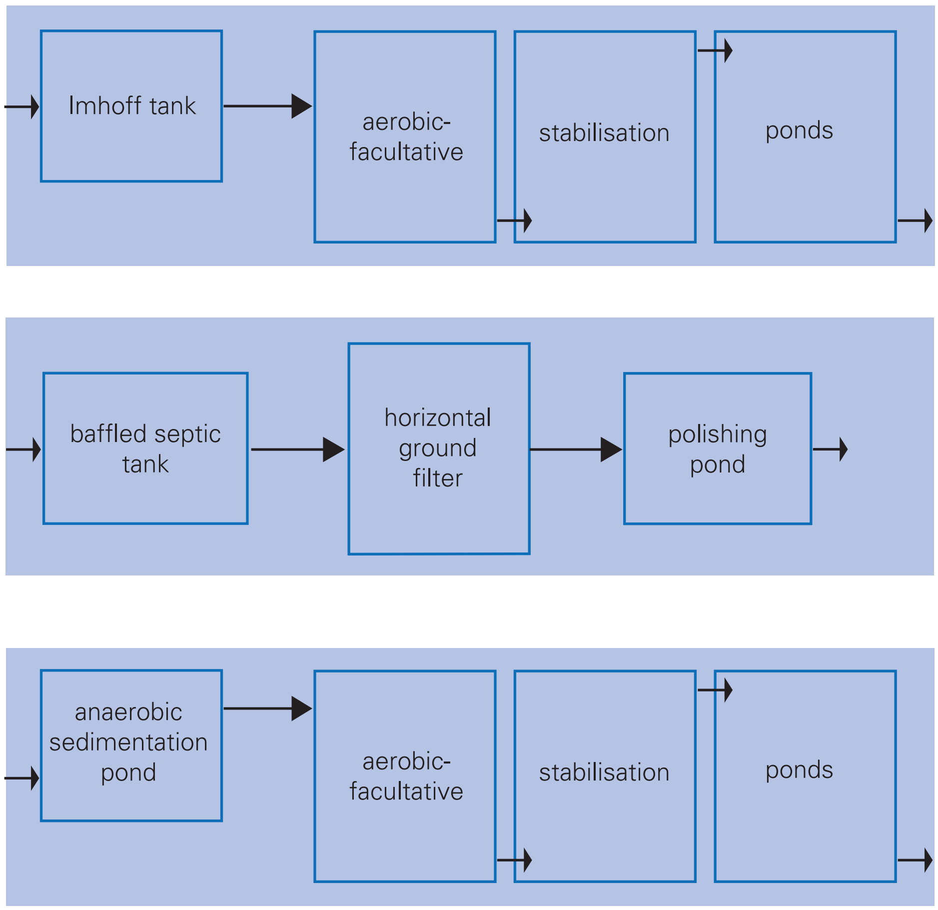
→ settling →	anaerobic digestion →	aerobic and facultative degradation →	aerobic polishing, final sedimentation →
septic tank, Imhoff tank	anaerobic filter baffled septic tank biogas plant	ground filter, aerobic-facultative stabilisation pond	polishing pond

Picture 9_38: The complete treatment chain of DEWATS-technology

Apart from applying different DEWATS technologies in series, hybrid systems can also combine different technologies within one treatment unit. One can, for ex–ample, combine the baffled septic tank with the anaerobic filter by adding filters in the last chambers of the baffled septic tank (see picture 9_39); alternatively, if a floating-filter medium is available, one may provide a thin filter layer at the top of each baffled chamber. In practice, the combination of six baffled chambers with two filter chambers has performed reliably and well.



Picture 9_39 An example of a hybrid and combined reactor



Picture 9_40: Typical combinations for full treatment with DEWATS-technology

10 Designing DEWATS

If the planning engineer knows his or her craft and recognises his or her limitations, designing DEWATS is relatively simple. Treatment-system performance cannot be precisely predicted and, therefore, calculating of dimensions should not involve ambitious procedures; in the case of small- and medium-scale DEWATS, a slightly oversized plant volume adds to operational safety.

Based on local conditions, needs and preferences, plants of varying sizes can be chosen as standard designs. On-site adaptations can then be made by less-qualified site supervisors or technicians.

In the case of specific demands, calculations and design must be carried out individually; the structural details of the standardised plants can be integrated. In this chapter we introduce a simplified, quasi-standardised method of calculating dimensions using spreadsheets.

Co-operative plant systems that require interconnecting sewerage must be designed individually by an experienced engineer, who is able to place plants and sewers according to contours and other site requirements.

10.1 Technical spreadsheets – background

10.1.1 Usefulness of computer calculation

The purpose of this chapter is to provide the engineer with tools to produce his or her own spreadsheets for sizing DEWATS in any computer programme that he or she is familiar with. The exercise of producing one's own tables will compel engineers to deepen their understanding of design.

The curves that have been used as the basis for calculation in the formulas applied in the computer spreadsheets may also be of interest to those who do not use a computer (these are found in this chapter). As these curves visualise the most important relationships between various parameters, they will enhance understanding of the factors that influence the treatment process. It should be noticed that the graphs have been developed on the basis of mixed information; the methods of calculation, therefore, do not always follow the same logic.

Computerised calculations can be very helpful, particularly if the formulas and the input data are correct. Flawed assumptions or wrong data, on the other hand, will definitely result in worthless results. Nevertheless, assuming the correct input data is, spreadsheets provide a quick impression of the plant's space requirement and what treatment performance can be expected. Ready-to-use computer spreadsheets are especially helpful to those who do not design DEWATS on a daily basis and would otherwise need to recollect the entire theory for sizing a plant before starting to design.

Please bear is mind that DEWATS provides a set of approaches. Because of the very different parameters that are relevant for the performances of a plan (temperature, materials to be used, composition of the wastewater etc.) there is not a 'right way' to calculate dimensions. Ist is the experience and understanding of the planner that is crucial to create the designs most appropriate to local conditions – i. e. the wastewater problem.

10.1.2 Risks of using simplified formulas

The formulas applied in the spreadsheets have been developed by practitioners, who are not overly concerned with theoretical knowledge. But the formulas are based on scientific findings, which have been simplified in the light of of practical experience.

Even if the formulas were to be 100% correct, the results would not be 100% accurate, as input data is not fully reliable. But the accuracy of the formulas is likely to be greater than the accuracy of wastewater sampling and analysis. There are many unknown factors influencing treatment efficiency and "scientific" handbooks provide a possible range of results. But this book, althaph "scientifically" based, is written for people who have to build a real plant out of real building materials. The supervisor cannot tell the mason to make a concrete tank "about 4.90 m to 5.60 m long"; he or she must say: "The length should be 5.35 m". The following spreadsheets were designed in this spirit. Anyone who already uses more variable methods of calculation and who is not the target reader of this book is free to modify the formulas and curves according to his or her experience and ability (the authors welcome any information that would help to improve the spreadsheets).

As the formulas represent simplifications of complex natural processes, there is a certain risk that they do not reflect reality adequately. However, the risk of changes in the assumed reality is even greater; for example, expanding a factory without enlarging the treatment system is obviously more significant than an assumed BOD of 350 mg/l, when in reality it is only 300 mg/l.

Listed below are some examples of incorrect assumptions and their consequences:

- Underestimating sludge accumulation in septic tanks, sedimentation ponds, Imhoff tanks and anaerobic reactors results in shorter desludging intervals
- In the case of anaerobic reactors, severe under-sizing could lead to a collapse of the process, while over-sizing may require longer maturation time at the beginning
- Incorrect treatment performance of primary or secondary treatment steps could be the cause of over- or undersized post-treatment facilities. This may result in unnecessarily high investment costs, having to enlarg the post treatment facilities
- Undersized anaerobic ponds will develop odour, while slightly oversized ponds may not develop sufficient scum, also resulting in smells
- Undersized aerobic ponds can develop a odour; there is no harm in oversizing aerobic ponds
- The biggest risk lies in filter media clogging in both anaerobic tanks and constructed wetlands. However, the risk is more likely to come from inferior filter material, faulty structural details or incorrect wastewater data than from incorrect sizing

In general, moderate oversizing reduces the risk of unstable processes and inferior treatment results.

10.1.3 About the spreadsheets

The spreadsheets presented in this handbook are in Microsoft EXCEL; other suitable programmes may also be used.

There might be differences in the syntax of formulas, for example 3^2 (3 to the power of 2) may be written as =POWER(3;2) or =3x2, square root of 9 could be =SQRT(9) or =9x1/2, cubic root of 27 would be =power(27;1/3) or =27x1/3. Some programmes may accept only one of the alternatives.

The spreadsheets are based on data which is normally available to the planning engineer within the context of DEWATS. For example, while the measurement of BOD_5 and COD may be possible at the beginning of planning, it is unlikely that the BOD_5 will be regularly controlled later on. Therefore, calculations are based on COD or the results of BOD-based formulas have been set in relation to COD, and vice versa. In the following, the term BOD stands for BOD_5.

The formulas applied in the spreadsheets are based on curves from scientific publications, handbooks and the experience of BORDA and its partners. The formulas, therefore, define typical trends. For example, it is wellknown that the removal efficiency of an anaerobic reactor increases when the COD/BOD ratio is narrow. Such curves have been simplified into a chain of straight lines to allow the reader to easily understand the formulas – and to adjust their values to local conditions if necessary. Although the amount of data on which some of these curves are based is sometimes too insignificant to be statisticaly relevant, the formulas have been applied successfully and adjusted on the basis of practical experience.

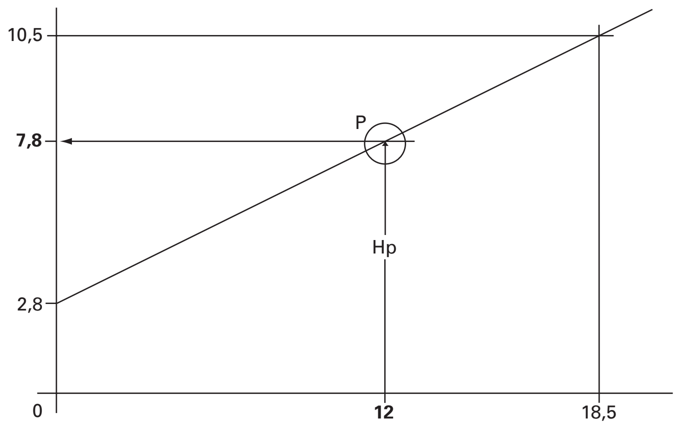
The formulas are simple. Besides basic arithmetical operations, they use only one logical function, namely the "IF"-function. For example:

> If temperature is less than 20°C; then hydraulic retention time is 20 days; if not, then it is 15 days in case the temperature is less than 25°C; otherwise (this means, if temperature is over 25°C) the HRT is 10 days.

Assuming the temperature is stated in cell F5 of the spreadsheet, the formula for retention time will be written as: =IF(F5<20;20;IF(F5<25;15;10)).

The formulas have been kept simple, so that the user can make modifications, according to experience or superior knowledge. For example, if it has been found that, for a certain substrate, the HRT should be 25 days below 20°C, 23 days up to 25°C and 20 days above 25°C and, that for safety reasons, 10% longer retention time is added, then the formula should read:

= 110%* IF (F5 < 20; 25; IF (F5 < 25; 23; 20)).



Hp = (12 x (10,5-2,8)/18,5) + 2,8 = 7,8

Picture 10_1: The graphical expression of the "rule of three"

Values between defined days or amounts may be calculated by using the famous "rule of three", of which there are plenty of examples in the following tables. The slope of a straight line is expressed in its tangent; the height of a certain point is found by multiplying the length with the ratio of the slope, i.e. total height divided by total length (Picture 10_1).

In case the reader is not familiar with working in EXCEL, it is better not to modify formulas but to manipulate the results by entering "modified" data. For example, if the values of spreadsheet results are generally lower or higher than the experienced in the field, dimensioning can be adjusted by entering lower or higher temperature values, or shorter or longer retention times. One could also multiply wastewater volumes or COD concentrations by a safety factor before starting the calculation. To avoid mishaps, all the spreadsheet cells should be locked, except the ones written in bold figures.

When the user prepares his or her own tables and copies the formulas below, the columns (A; B; C; D...) and the rows (1; 2; 3; 4; 5...) before the "equals" symbol of each formula, define which cell the formula should be written in. The names of cells and rows are shown on the entry mask of the monitor. In transferring formulas to the spreadsheet, the cell name before the "equals" symbol should not be copied; for example E6=D5/E5 is to be written in cell E6 as =D5/E5.

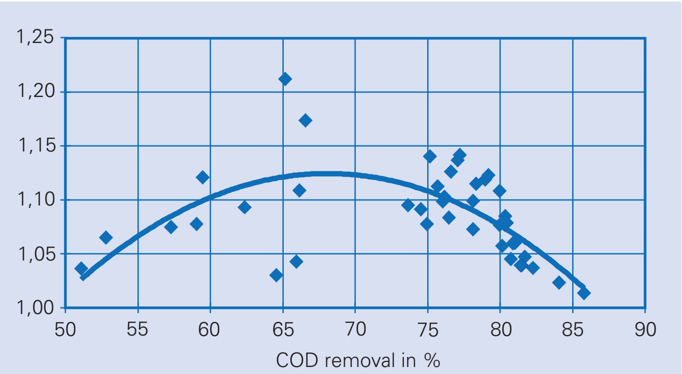
The italic figures are either guiding figures to show usual values, or they indicate limits to be observed. The bold figures are those which have to be filled in by hand; the other figures are calculated. Columns which are labelled “given” contain data which reflects a given reality, for example, wastewater-flow volume or wastewater strength. Columns which are labelled “chosen” contain data which may be modified to optimise the design, for example, hydraulic retention time or desludging intervals. All other cells contain formulas and should be locked, in order to avoid deleting by accident formulas. Cells which are labelled "check" or "require" should be used to confirm whether the chosen and given values are realistic.

10.2 Technical spreadsheets – application

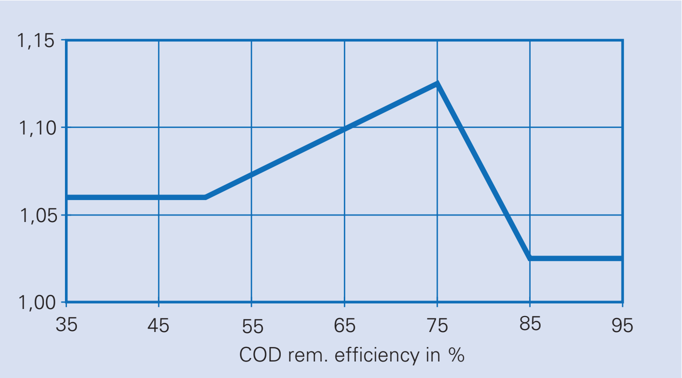
10.2.1 Assumed COD/BOD ratio

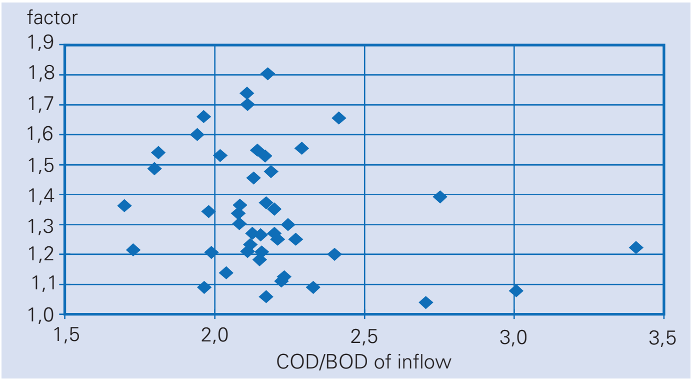
The COD/BOD ratio widens during biological treatment because the BOD reflects only that part of the oxygen demand which is reduced by biological treatment, while the COD represents total oxygen demand. The removed BOD, therefore, has a greater percentage-wise influence on the change of the BOD than on the COD. The COD/BOD ratio widens faster while biological degradation is incomplete, and slower when treatment efficiency reaches almost 100%.

Picture 10_2:
COD removal in relation to temperature in anaerobic reactors.
Change of COD/BOD ratio during anaerobic treatment. The samples have been taken by SIITRAT from anaerobic filters, most of them serving schools in the suburbs of Delhi, India



Picture 10_3:
COD removal relative to wastewater strength in anaerobic filters.
Simplified curve of Picture 10_2, which is used in the spreadsheet formulas





Picture 10_4: Illustration to spreadsheet for calculation of anaerobic filter dimensions. Changes of COD/BOD ratio during anaerobic treatment of domestic wastewater. The samples were taken by SIITRAT. The few sample points of high COD/BOD ratio (to the right of the graph) stem from a post-treatment plant and are not comparable to the majority of samples

10.2.2 Domestic Wastewater Quantity and Quality

The following spreadsheet (see Table 24) helps to define domestic wastewater in terms of the number of people and the wastewater they discharge. BOD and water-consumption figures vary widely from place to place and, therefore, should be obtained for each site.

Formulas of spreadsheet "wastewater per capita":

E5 = A5 x C5 / 1000

F5 = A5 x B5 / E5

G5 = D5 x F5

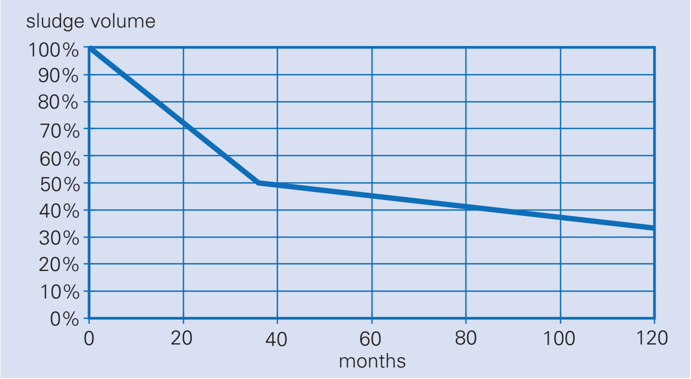
	A	B	C	D	E	F	G
1	Wastewater production per capita						
2	user	BOD_5 per user	water consump. per user	COD/BOD_5 ratio	daily flow of wastewater	BOD_5 concentr.	COD concentr.
3	given	given	given	given	calculated	calculated	approx.
4	number	g/day	litres/day	mg/l	m³/day	mg/l	mg/l
5	**80**	**55**	**165**	**1.90**	13.20	333	633
6	*range =>*	*40 - 65*	*50 - 300*				

Table 24: Spreadsheet for calculation of quantity and quality of domestic-waste–water production

10.2.3 Septic tank

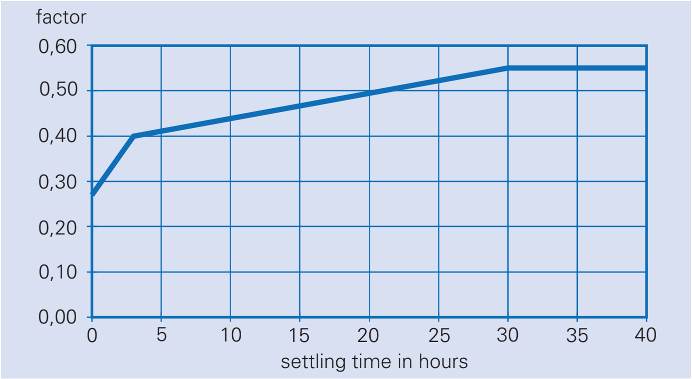
The size of septic tanks is standardised in most countries. In the case of DEWATS, however, the wastewater may not be the standard domestic wastewater. The spreadsheet (see Table 25) assists in the design of septic tanks. Flow volume, number of peak hours of flow and pollution load are the basic entries. "Chosen" parameters include the desludging interval and the HRT; the former is decisive for the digester volume for sludge storage, while the latter decides the volume of the liquid.

As sludge compacts with time, the formulas in the spreadsheets are based on the graph shown in Picture 10_5.

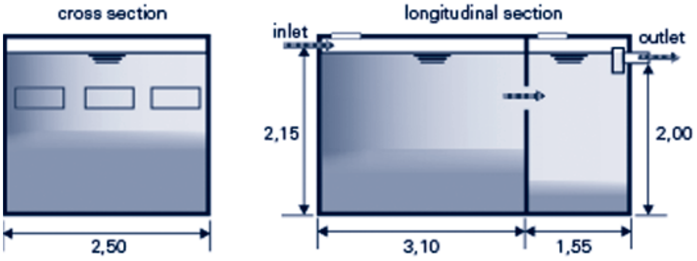


Picture 10_5: Reduction of sludge volume during storage

COD removal rates in settlers and septic tanks depend on the amount of settleable solids, their COD content and the intensity of inoculation with fresh inflow. The contact between fresh incoming substrate and active sludge in Imhoff tanks is nearly zero, while in sedimentation ponds with a deep inlet, it is intensive. This fact has been taken into consideration by dividing the parameter "settleable SS per COD" by an experience factor of between 0.50 and 0.60. The general tendency is shown in the graph Picture 10_6.



Picture 10_6:
COD removal in settlers



Picture 10_7:
Illustration to spreadsheet for calculation of septic tank dimensions

Formulas of spreadsheet "septic tank"

	A	B	C	D	E	F	G	H	I	J
1	General spreadsheet for septic tank, input and treatment data									
2	daily waste-water flow	time of most waste-water flow	max. flow at peak hours	COD inflow	BOD_5 inflow	HRT inside tank	settleable SS/COD ratio	COD removal rate	COD outflow	BOD_5 outflow
3	given	given	calcul.	given	given	**chosen**	given	calcul.	calcul.	calcul.
4	m³/day	h	m³/h	mg/l	mg/l	h	mg/l	%	mg/l	mg/l
5	**13.0**	**12**	1.08	**633**	**333**	**18**	**0.42**	35%	411	209
6	COD/BOD_5 ->				1.90	12 - 24 h	0.35 - 0.45 domestic		BOD rem. ->	1.06
7	dimensions of septic tank									
8	desludging interval	inner width of septic tank	min. water depth at outlet point	inner length of first chamber		length of second chamber		volume incl. sludge	actual volume of septic tank	biogas 70% CH_4 50% dis-solved
9	chosen	chosen	chosen	requir.	chosen	requir.	chosen	requir.	check	calcul.
10	months	m	m	m	m	m	m	m³	m³	m³/d
11	12	2.50	2.00	3.13	3.10	1.56	1.55	23.46	23.25	0.72
12	sludge l/g BOD rem.							0.0042		

Table 25: Spreadsheet for calculating septic tank dimensions

C5=A5/B5

H5 = G5 / 0.6 x IF (F5 < 1; F5 x 0.3; IF (F5 < 3; (F51) x 0.1/2 + 0.3;
IF (F5 < 30; (F5 - 3) x 0.15/27 + 0.4; 0.55)))

The formula relates to Picture 10_6. The number 0.6 is a correction factor based on practical experience.

I5 = (1 - H5) x D5

J5 = (1 - H5 x J6) x E5

E6 = D5 / E5

J6 = IF (H5 < 0.5; 1.06; IF (H5 < 0.75; (H5 - 0.5) x 0.065 / 0.25 + 1.06;
IF (H5 < 0.85;1.125 - (H5 - 0.75) x 0.1 /0.1; 1.025)))

The formula relates to Picture 10_3.

D11 = 2/3 x H11 / B11 / C11

F11 = D11 / 2

H11 = IF (H12 x (E5 - J5) / 1000 x A11 x 30 x A5 + C5 x F5 < 2 x A5 x F5 / 24; 2 x A5 x F5 / 24; H12 x (E5 - J5) / 1000 x A11 x 30 x A5 + C5 x F5) + 0.2 x B11 x E11

The formula takes into account that sludge volume is less than half the total volume.

I11 = (E11 + G11) x C11 x B11

J11 = (D5 - I5) x A5 x 0.35 / 1000 / 0.7 x 0.5

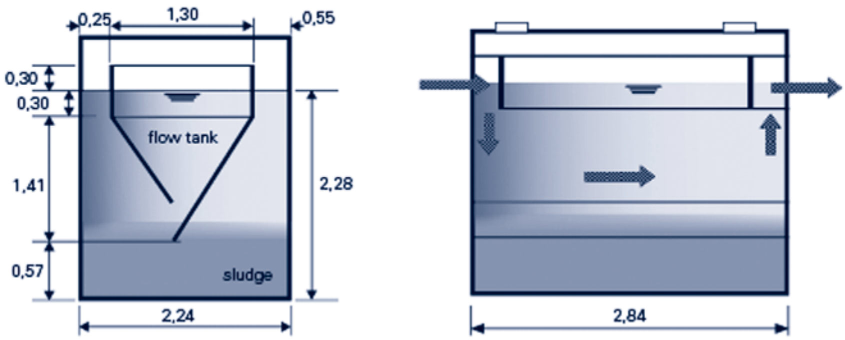
350 l methane are produced from each kg COD removed.

H12 = 0.005 x IF (A11 < 36; 1 - A11 x 0.014; IF (A11 < 120; 0.5 - (A11 - 36) x 0.002; 1/3))

The formula relates to Picture 10_5.

10.2.4 Imhoff tank

The general treatment properties in the Imhoff tank are comparable to those in any other settler. Since wastewater does not come into direct contact with active sludge, BOD removal from the liquid is almost zero; however, as sedimentation is greater than in other settlers, the COD or BOD removal within these units is comparable. This fact is reflected in the factor 0.50 of cell H5.



Picture 10_8: Illustration to spreadsheet for calculation of Imhoff Tank dimensions

Flow volume, number of peak hours of flow and pollution load are the basic entries for calculation. "Chosen" parameters are the same as those for the septic tank – HRT and desludging intervals.

Formulas of spreadsheet "Imhoff tank"

	A	B	C	D	E	F	G	H	I	J
1	General spreadsheet for Imhoff tank, input and treatment data									
2	daily waste-water flow	time of most waste-water flow	max. flow at peak hours	COD inflow	BOD_5 inflow	HRT inside flow tank	settleable SS/COD ratio	COD removal rate	COD outflow	BOD_5 outflow
3	given	given	calcul.	given	given	**chosen**	given	calcul.	calcul.	calcul.
4	m³/day	h	m³/h	mg/l	mg/l	h	mg/l	%	mg/l	mg/l
5	**25.0**	**12**	2,08	**633**	**333**	**1.50**	**0.42**	27%	460	237
6				COD/BOD_5 ->	1.90	domestic 0.35 - 0.45			BODrem. ->	1.06
7	dimensions of Imhoff tank									
8	desludging interval	flow tank volume	sludge volume	inner width of flow tank	space be-side flow tank	total inner width of Imhoff tank	inner length of Imhoff tank	sludge height	total depth at outlet	biogas 70% CH_4 50% dis-solved
9	**chosen**	calcul.	calcul.	**chosen**	**chosen**	calcul.	calcul.	calcul.	calcul.	calcul.
10	months	m³	m³	m	m	m	m	m	m	m³/d
11	**12**	3.13	3.61	**1.30**	**0.55**	2.24	2.82	0.57	2.28	1.08
12	sludge l/g BODrem.		0.0042							

Table 26:
Spreadsheet for calculating Imhoff tank dimensions

C5 = A5/B5

H5 = G5 / 0.5 x IF (F5 < 1; F5 x 0.3; IF (F5 < 3; (F5 - 1) x 0,1 / 2 + 0.3 ;

IF (F5 < 30; (F5 - 3) x 0.15 / 27 + 0.4; 0.55)))

The formula relates to 10_6. The number 0.5 is a correction factor based on practical experience.

I5 = (1 - H5) x D5

J5 = (1 - H5 x J6) x E5

E6 = D5 / E5

J6 = IF (H5 < 0.5; 1.06; IF (H5 < 0,75; (H5 - 0.5) x 0.065 / 0.25 + 1.06;
IF (H5 < 0.85; 1.125 - (H5 - 0.75) x 0.1 / 0.1; 1.025)))

The formula relates to Picture 10_3.

B11 = C5 x F5

C11 = A5 x 30 x A11 x C12 x (E5 – J5) / 1000

F11 = D11 + E11 + 0,25 + 2 x 0,07

All formulas for dimensions relate to the geometry of the Imhoff tank, as shown in Picture 10_8.

G11 = B11 / (0.3 x D11 + (D11 x D11 x 0.85 / 2))

H11 = C11 / F11 / G11

I11 = H11 + 0.85 x D11 + 0.3 + 0.3

J11 = (D5 - I5) x A5 x 0.35 / 1000 / 0.7 x 0.5

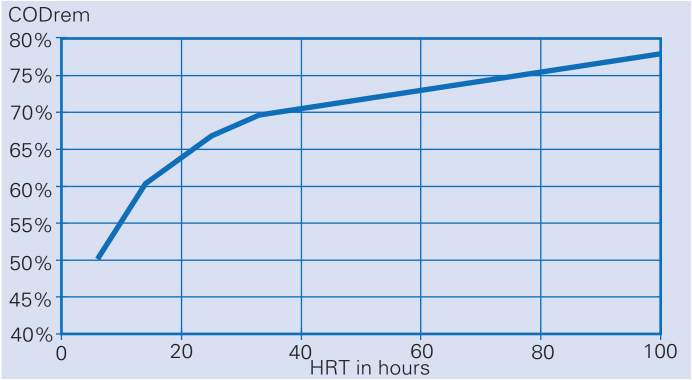
350 l methane are produced from each kg COD removed.

C12 = 0,005 x IF (A11 < 36;1 - A11 x 0.014; IF (A11 < 120; 0.5 - (A11 - 36) x 0.002;1/3))

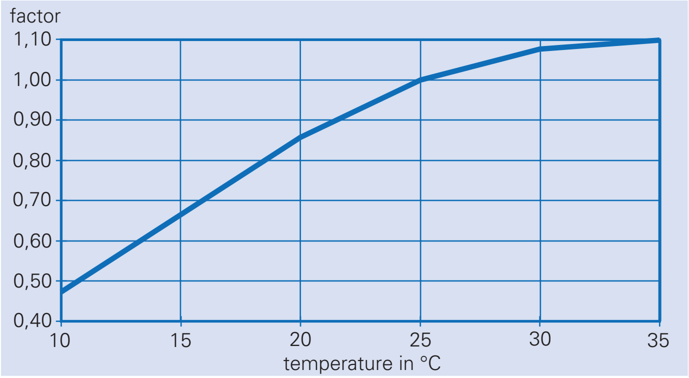
The formula relates to Picture 10_5.

10.2.5 Anaerobic filters

Volume of flow and pollution load are the basic entries for calculation. The "chosen" parameters for the anaerobic filter are the hydraulic retention time and desludging intervals. The calculation of performance is based on a curve, which describes the relation between hydraulic retention time and percentage of COD removal. The curve (Picture 10_9) is based on a COD of 1500 mg/l at 25°C. The values are then multiplied by factors reflecting temperature (Picture 10_10), wastewater strength (Picture 10_11) and specific-filter surface (Picture 10_12).

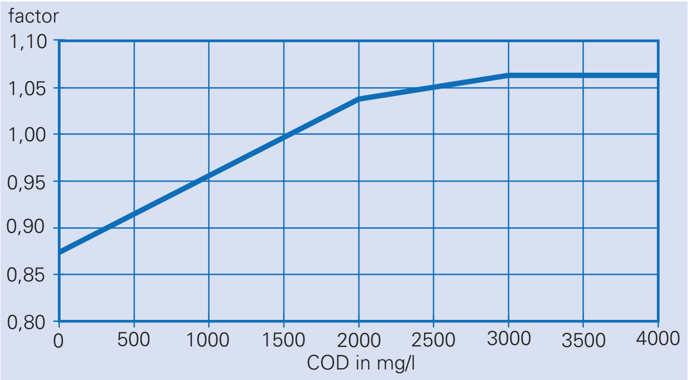


Picture 10_9:
COD removal in relation to HRT in anaerobic filters

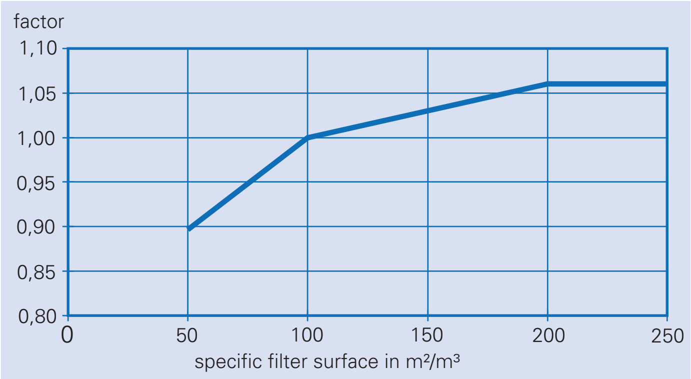


Picture 10_10:
COD removal in relation to temperature in anaerobic reactors

The void space of the filter medium influences the digester volume required to provide sufficient hydraulic retention time. Gravel has approximately 35% void space, while specially manufactured plastic pieces may have over 90%. When filter height is increased together with total water depth, the impact of increased depth on HRT is less with gravel than with plastic pieces. While filter height remains the same, the distance from filter bottom to digester floor must be increased.



Picture 10_11: COD removal relative to wastewater strength in anaerobic filters



Picture 10_12: Spreadsheet for calculating anaerobic-filter dimensions

	A	B	C	D	E	F	G	H	I	J	K	L
1	General spreadsheet for anaerobic filter (AF) with integrated septic tank (ST)											
2	daily waste water flow	time of most waste water flow	max. peak flow per hour	COD inflow	BOD_5 inflow	$SS_{settl.}$/ COD ratio	lowest digester tempera-ture	HRT in septic tank	de-sludging interval	COD-removal septic tank	BOD_5 removal septic tank	BOD/ COD-removal factor
3	given	given	calcul.	given	given	given	given	**chosen**	**chosen**	calcul.	calcul.	calcul.
4	m³/day	h	m³/h	mg/l	mg/l	mg/l	°C	h	month	%	%	ratio
5	**25.0**	12	2.08	**633**	**333**	**0.42**	**25**	**2**	**36**	25%	26%	1,06
6	COD/BOD_5 ->			1.90	0,35 - 0.45 (domestic)			2h			$BOD_{rem.}$ -> 1.06	
7	treatment data											
8	COD inflow in AF	BOD_5 inflow into AF	specific surface of filter medium	voids in filter mass	HRT inside AF reactor	factors to calculate COD-removal rate of anaerobic filter				COD-removal rate (AF only)	COD outflow of AF	COD-removal rate of total system
9	calcul.	calcul.	given	given	**chosen**	calculated according to graphs				calcul.	calcul.	calcul.
10	mg/l	mg/l	m²/m³	%	**h**	f-temp	f-strength	f-surface	f-HRT	%	mg/l	%
11	478	247	**100**	**35%**	**30**	1,00	0,91	1,00	69%	70	142	78%
12			80 - 120	30 - 45	24 - 48 h							
13	dimensions of septic tank											
14	BOD/ COD removal factor	BOD_5 rem. rate of total system	BOD_5 outflow of AF	inner width of septic tank	min. wa-ter depth at inlet point	inner length of first chamber		length of second chamber		sludge accum.	volume incl. sludge	actual volume of septic tank
15	calcul.	calcul.	calcul.	**chosen**	**chosen**	calcul.	**chosen**	calcul.	**chosen**	calcul.	**requir.**	calcul.
16	ratio	%	mg/l	m	**m**	m	m	m	m	l/kg BOD	m³	m³
17	1.10	85	49	**1.75**	**2.25**	1,69	1.70	0.85	**0.85**	0,00	10.00	10.04
18	sludge l/g BODrem.											
19	dimension of an aerobic filter							bio gas production			check!	
20	volume of filter tanks	depth of filtertanks	length of each tank	number of filter tanks	width of filter tanks	space below perfora-ted slabs	filter high (top 40 cm below water-level)	out of septic tank	out of anaerobic filter	total	org. load on filter volume COD	max. up-flow velocity inside filter voids
21	calcul.	**chosen**	calcul.	**chosen**	**requir.**	**chosen**	calcul.	assump.: 70% CH_4: 50% dissolved			calcul.	calcul.
22	m³	m	m	No.	m	m	m	m³/d	m³/d	m³/d	kg/m³*d	m/h
23	31.25	**2.25**	2.25	**3**	2.69	**0.60**	1.20	0.97	2.10	3.07	1.57	0.98
24	max.!!										< 4.5	<2.0

Table 27:
Spreadsheet for calculating anaerobic-filter dimensions

Formulas of spreadsheet "anaerobic filter"

```
C5 = A5 / B5

J5 = F5 / 0.6 x IF (H5 < 1;H5 x 0.3; IF (H5 < 3; (H5 - 1) x 0,1 / 2 + 0.3;
IF(H5 < 30; (H5 - 3) x 0.15 / 27 + 0.4; 0.55)))
```

The formula relates to Picture 10_6. The number 0.6 is a correction factor based on practical experience.

```
K5 = L5 x J5

L5 = IF (J5 < 0.5; 1,06; IF (J5 < 0.75; (J5 - 0.5) x 0.065 / 0.25 + 1.06;
IF (J5 < 0.85; 1,125 - (J5 - 0.75) x 0.1/0.1; 1.025)))
```

The formula relates to Picture 10_3.

```
D6 = D5 / E5

A11 = D5 x (1 - J5)

B11 = E5 x (1 - K5)

F11 = IF (G5 < 20; (G5 - 10) x 0.39 / 20 + 0.47; IF(G5<25; (G5 - 20) x 0.14 / 5 + 0.86;
IF (G5 < 30; (G5 - 25) x 0.08 / 5 + 1;1.1)))
```

The formula relates to Picture 10_10.

```
G11 = IF (A11 < 2000; A11 x 0.17 / 2000 + 0.87;
IF (A11 < 3000; (A11 - 2000) x 0.02 / 1000 + 1.04; 1.06))
```

The formula relates to Picture 10_11.

```
H11 = IF (C11 < 100; (C11 - 50) x 0.1 / 50 + 0.9; IF (C11 < 200; (C11 - 100) x 0.06 / 100 + 1; 1.06))
```

The formula relates to Picture 10_12.

```
I11 = IF (E11 < 12; E11 x 0.16 / 12 + 0.44; IF (E11 < 24; (E11 - 12) x 0.07 /12 + 0.6;
IF (E11 < 33; (E11 - 24) x 0.03 / 9 + 0.67; IF (E11 < 100; (E11 - 33) x 0.09 / 67 + 0.7; 0.78))))
```

The formula relates to Picture 10_9.

```
J11 = IF (F11 x G11 x H11 x I11 x (1 + (D23 x 0,04)) < 0.98;
F11 x G11 x H11 x I11 x (1 + (D23 x 0,04)); 0.98)
```

The formula considers improved treatment by increasing the number of chambers and limiting the treatment efficiency to 98%.

```
K11 = A11 x (1 - J11)

L11 = (1 - K11 / D5)

A17 = IF (L11 < 0.5; 1.06 ; IF (L11 < 0.75; (L11 - 0.5) x 0.065 / 0.25 + 1.06;
IF(L11 < 0.85; 1.125 - (L11 - 0.75) x 0.1 / 0.1; 1.025)))
```

The formula relates to Picture 10_3.

```
B17 = L11 x A17

C17 = (1 - B17) x E5

F17 = 2/3 x K17 / D17 / E17

H17 = F17 / 2

J17 =0,005 x IF (I5 < 36;1 - I5 x 0.014; IF (I5 < 120; 0.5 - (I5 - 36) x 0.002; 1/3))
```

The formula relates to Picture 10_5.

```
K17 = IF (OR (K5 > 0;J5 > 0); IF(J17 x (E5 - B11) / 1000 x I5 x 30 x A5 + H5 x C5 < 2 x H5 x C5;
2 x H5 x C5; J17 x (E5 - B11) / 1000 x I5 x 30 x A5 + H5 x C5); 0)
```

The formula considers that the sludge volume is less than half of the total volume; a settler may be omitted.

L17 = (G17 + I17) x E17 x D17

A23 = E11 x A5 / 24

C23 = B23

E23 = A23 / D23 / ((B23 x 0.25) + (C23 x (B23 - G23 x (1 - D11))))

G23 = B23 - F23 - 0.4 - 0.05

H23 = (D5 - A11) x A5 x 0.35 / 1000 / 0.7 x0.5

350 l methane are produced from each kg COD removed.

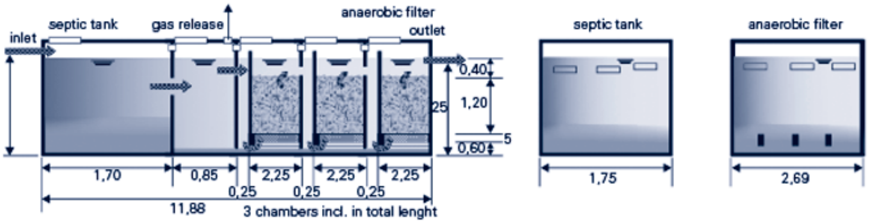
I23 = (A11 - K11) x A5 x 0.35 / 1000 / 0.7 x 0.5

350 l methane are produced from each kg COD removed.

J23= SUM (H23 : I23)

K23 = A11 x A5 / 1000 / (G23 x E23 x C23 x D11 x D23)

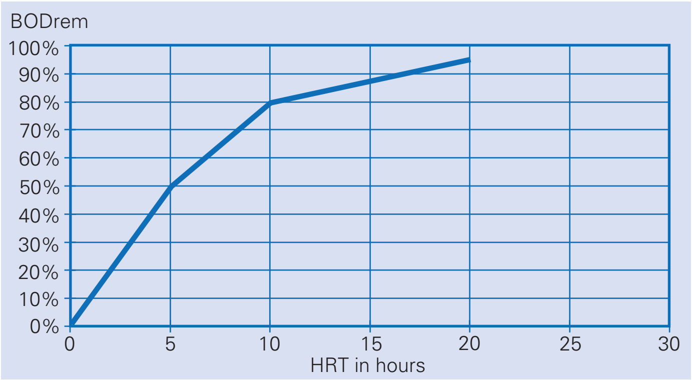
L23 = C5 / (E23 x C23 x D11)



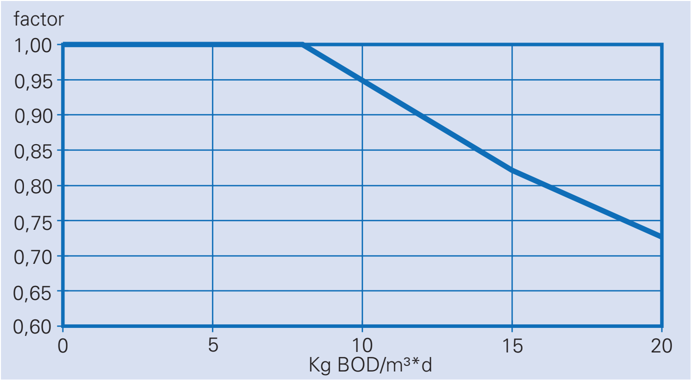
Picture 10_13: Illustration to spreadsheet for calculating anaerobic-filter

10.2.6 Baffled septic tank

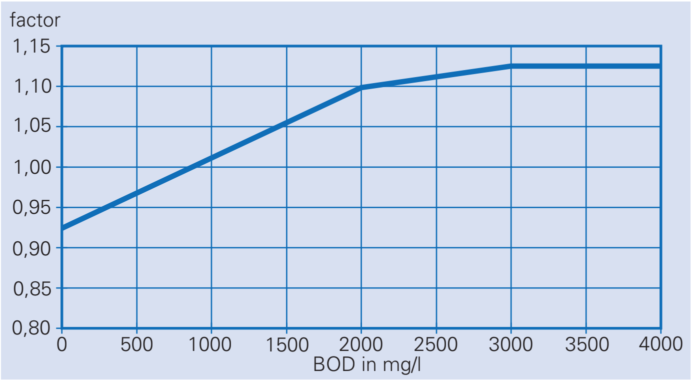
Volume of flow, number of peak hours of flow and pollution load are the basic entries for calculation. "Chosen" parameters for designing a baffled septic tank are the HRT, desludging intervals and the up-flow velocity (cell I17). Due to the interrelation between these factors, the HRT cannot be reduced by changing the dimensions of the up-flow chambers because the up-flow velocity will thereby be increased. To achieve the desired effluent quality, it is better to add another chamber than to enlarge their volumes because treatment efficiency increases with the number of chambers (see formula of cell J17). However, practical experience has shown that treatment efficiency does not increase with more than six chambers. Calculation is based on the curve (Picture 10_14) showing BOD removal for a BOD of 900 mg/l at 25°C. Factors are applied to adapt the calculation to wastewater strength (Picture 10_16) and temperature (Picture 10_10). An additional curve is used to prevent organic overloading (Picture 10_15).



Picture 10_14: BOD removal in relation to HRT in baffled septic tanks



Picture 10_15:
BOD removal affected by organic overloading in baffled septic tanks



Picture 10_16:
BOD removal in baffled septic tanks in relation to wastewater strength

	A	B	C	D	E	F	G	H	I	J	K
1	General spreadsheet for baffled septic tank with integrated settler										
2	daily waste-water flow	time of most waste-water flow	max. peak flow per hour	COD inflow	BOD_5 inflow	COD/BOD ratio	settleable SS / COD ratio	lowest digester tempera-ture	de-sludging interval	HRT in settler (no settler HRT=0)	COD removal rate in settler
3	avg.	given	max.	given	given	calcul.	given	given	chosen	chosen	calcul.
4	m³/day	h	m³/h	mg/l	mg/l	ratio	mg/l	°C	months	h	%
5	**25**	**12**	2.08	**633**	**333**	1.90	**0.42**	**25**	**18**	**1.50**	23%
6			COD/BOD_5 ->				0.35 - 0.45			1.5 h	
7	treatment data										
8	BOD_5 removal rate in settler	inflow into baffled reactor		COD/ BOD_5 ratio after settler	factors to calculate COD removal rate of anaerobic filter			COD rem. 25°, COD 1500	theor. rem. rate acc. to factors	COD rem. rate baffle only	COD out
9	calcul.	COD	BOD_5	calcul.	calculated according to graphs				calcul.	calcul.	calcul.
10	%	mg/l	mg/l	mg/l	f-overload	f-strenght	f-temp	f-HRT %	%	%	mg/l
11	24%	489	253	1.94	1.00	0.91	1.00	87	79%	81%	94
12	1.06	<- COD/ BOD removal factor						COD/BOD removal factor ->			1.025
13	dimensions of settler								baffled septic tank		
14	total COD removal rate	total BOD_5 removal rate	BOD_5 out	inner masonry measurements chosen acc. to required volume		sludge accum. rate	length of settler	length of settler	max. upflow velocity	number of upflow chambers	depth at outlet
15	calcul.	calcul.	calcul.	width	depth	calcul.	calcul.	chosen	chosen	chosen	chosen
16	%	%	mg/l	m	m	l/g COD	m	m	m/h	No.	m
17	85%	87%	42	**2.00**	**1.50**	0.0037	2.39	**2.40**	**1.8**	**5**	**1.50**
18									1.4 - 2.0 m/h		
19	dimensions of baffled septic tank							status and gp			
20	length of chambers should not exceed half depth		area of single upflow chamber	width of chambers		actual upflow velocity	width of downflow shaft	actual volume of baffled reactor	actual total HRT	org. load (BOD_5)	biogas (ass: CH_4 70%; 50% dissolved)
21	calcul.	chosen	calcul.	calcul.	chosen	calcul.	chosen	calcul.	calcul.	calcul.	calcul.
22	m	m	m²	m	m	m/h	m	m³	h	kg/m³*d	m³*/d
23	0.75	**0.75**	1.16	1.54	**2.00**	1.39	**0.25**	15.00	14	1.63	3.37
24								HRT reduced by 5% for sludge			

TIP: If removal rate is insufficient; increase number of upflow chambers to keep upflow velocity low.

Table 28
Spreadsheet for the calculation of baffled septic tank dimensions

Formulas of spreadsheet "baffled septic tank"

C5 = A5 / B5

F5 = D5 / E5

K5 = G5 / 0.6 x IF (J5 < 1; J5 x 0.3; IF (J5 < 3; (J5 - 1) x 0.1/2 + 0.3;
IF (J5 < 30; (J5 - 3) x 0,15 / 27 + 0.4;0.55)))

The formula relates to Picture 10_6. The number 0.6 is a correction factor based on practical experience.

A11 = K5 x A12

B11 = D5 x (1 - K5)

C11 = E5 x (1 - A11)

D11 = B11 / C11

E11 = IF (J23 < 8;1; IF (J23 < 15;1 - (J23 - 8) x 0.18 / 7; 0,82 - (J23 - 15) x 0.9 / 5))

The formula relates to Picture 10_15.

F11 = IF (B11 < 2000; B11 x 0.17 / 2000 + 0.87;
IF (B11 < 3000; (B11 - 2000) x 0.02 / 1000 + 1.04; 1.06))

The formula relates to Picture 10_16.

G11 = IF (H5 < 20; (H5 - 10) x 0.39 / 20 + 0.47; IF (H5 <25; (H5 - 20) x 0.14 /5 + 0.86;
IF(H5<30;(H5-25)x0.08/5+1;1.1)))

The formula relates to Picture 10_10.

H11 = IF(I23 < 5; I23 x 0.51 / 5; IF (I23 < 10; (I23 - 5) x 0.31 /5 + 0.51;
IF (I23 < 20; (I23 - 10) x 0.13 / 10 + 0.82; 0.95)))

I11 = E11 x F11 x G11 x H11

The formula relates to Picture 10_14.

J11 = IF (J17 < 7; E11 x F11 x G11 x H11 x (J17 x 0.04 + 0.82); E11 x F11 x G11 x H11 x 0.98)

The formula considers improved treatment by increasing the number of chambers and limiting the treatment efficiency to 98%.

K11 = (1 - J11) x B11

A12 = IF (K5 < 0,5; 1.06; IF (K5 < 0,75; (K5 - 0.5) x 0.065 / 0.25 + 1.06;
IF (K5 < 0.85; 1.125 - (K5 - 0.75) x 0.1 / 0.1; 1.025)))

The formula relates to Picture 10_3.

K12 = IF (A17 < 0.5; 1,06; IF (A17 < 0.75; (A17 - 0.5) x 0.065 / 0.25 + 1.06;
IF (A17 < 0.85; 1,125 - (A17 - 0.75) x 0.1 /0.1; 1.025)))

The formula relates to Picture 10_3.

A17=1-K11/D5

B17=A17xK12

C17=(1-B17)xE5

F17=0.005xIF(I5<36;1-I5x0.014;IF(I5<120;0.5-(I5-36)x0.002;1/3))

The formula relates to Picture 10_5.

G17 = IF (A11 > 0; IF (F17 x (E5 - C11) / 1000 x 30 x I5 x A5 + J5 x C5 < 2 x J5 x C5;
2 x J5 x C5; F17 x (E5 - C11) / 1000 x 30 x I5 x A5 + J5 x C5); 0) / D17 / E17

The formula considers that sludge volume is less than half of the total volume; a settler may be omitted.

A23 = K17 x 0.5

C23 = C5 / I17

D23 = C23 / B23

F23 = C5 / B23 / E23

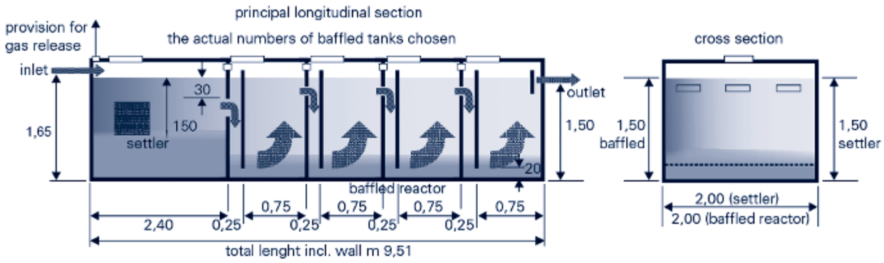
H23 =(G23 + B23) x J17 x K17 x E23

I23 = H23 / (A5 / 24) / 105%

J23 = B11 x C5 x 24 / H23 / 1000

K23 = (D5 - K11) x A5 x 0.35 / 1000 / 0.7 x 0.5

350 l methane are produced from each kg COD removed.



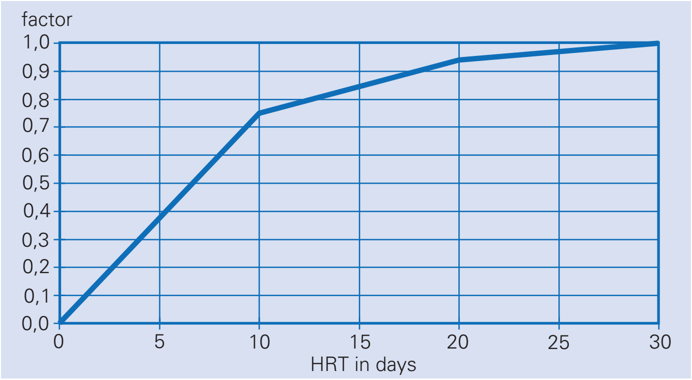
Picture 10_17:
Illustration to spreadsheet for calculation of baffled septic tank dimensions

10.2.7 Fully mixed digester

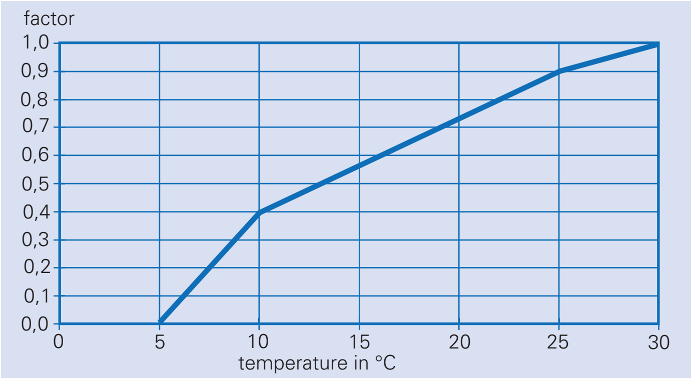
Within a fully mixed digester, or biogas plant, as it is commonly known in rural households India, cattle dung is thoroughly mixed with water. Even as effluent, the substrate is very viscous; very little sludge settles and, as a result, no sludge must be removed for many years. The same type of rural biogas plant in China receives a substrate which is a mixture of human excreta, pig dung and water – homogeneous by far in India. Other wastewater, for example from slaughter than houses, may have different properties again. It is difficult, therefore, to calculate dimensions for the many different kinds of "strong" wastewater, for which biogas treatment might be suitable. The following spreadsheet should be used with certain reservations and – formulas may need to be adapted to locally.

The spreadsheet conditions does reveal, however, the influencing factors.
The formulas are based on the following assumptions:

- Solids which settle within one day of benchmark testing represent 95% of all settleable solids
- There is a mixing effect inside the digester because of the relatively high gas production, which prevents sludge from settling. Any additional sludge will only make up for the loss in volume by compression. Thus, the accumulating sludge volume is equal to the amount calculated from the one day of bench-mark testing
- All settleable and non-settleable solids will digest within hydraulic retention times typical for sludge reactors
- 95% of their BOD is removed after 25 days and 30°C; this is equivalent to 400 l of biogas produced from 1 kg of organic dry matter



Picture 10_18: Gas production of fixed-dome biogas plants in relation to HRT



Picture 10_19: Gas production of fixed-dome biogas plants in relation to temperature

Formulas of spreadsheet "fully mixed digester"

D5 = B5 x C5

I5 = IF (F5 < 10; F5 x 0.75 / 10; IF (F5 < 20; (F5 - 10) x 0.19 / 10 + 0.75; (F5 - 20) x 0.06 / 10 + 0.94))

The formula relates to Picture 10_18.

J5 = IF (G5 < 5; 0; IF (G5 < 10; (G5 - 5) x 0.4 / 5;
IF (G5 < 25; (G5 - 10) x 0.5 / 15 + 0.4; (G5 - 25)x 0.1 / 5 + 0.9)))

The formula relates to Picture 10_19.

K5 = H5 x I5 x J5 x A5 x D5

B11 = 1.1 x ((1000 x K5 x L5 / A11 / 0.35) / (0.95 x I5 x J5)) x (1 - 0.95 x I5 x J5) / A5

The formula determines the influent COD and calculates the COD removal by assuming a production of 350 l methane per kg COD removed; the additional 10% represent the anorganic COD, which is not removed.

D11 = 30 x C11 x A5 x E5 / 1000

E11 = F5 x A5

F11 = D11 + E11

H11 = K5 x G11

L11 = 2 x SQRT ((H11 / J11 - (K11 / 2) x (K11 / 2) x PI()) / PI())

The mathematical expression is:

D17 = A17 - B17 / 2

E17 = H11 / (D17 x D17 x PI())

The mathematical expression is:

H11 / (D17² x ϖ)

F17 = (F11 - POWER (A7 - B17 - C17; 2) x PI() x E17) / (A17 x A17 x PI()) + E17

The mathematical expression is:

G17 = E17 + 0.15

H17 = F17 + 0.15

I17 = 3,14 x I11 x I11 x (K17 - I11 / 3)

J17 = 0,02 + POWER ((F11 + H11/2 + I17) / 4.19; 1/3)

The theoretical digester volume is taken as the volume below the zero line plus half the gas storage; 0.02 m are added for plaster.

The mathematical expression is:

; 4,19 is 4/3ϖ

L17 = 4.19 x (K17 - 0.02) x (K17 - 0.02) x (K17 - 0.02) - I17 - H11 / 2

B23 = PI() x (I11 + A23) x (I11 + A23) x (K17 - (I11 + A23) / 3)

The volume above the lowest slurry level is found by trial and error; ϖ is expressed as PI().

C23 = I17 + H11

D23 = A23 + J11

E23 = 3.14 x I11 x I11 x (G23 - I11/3)

F23 = 0.02 + POWER ((F11 + H11/2 + E23) / 2.09; 1/3)

The mathematical expression is:

; 2.09 is 2/3ϖ

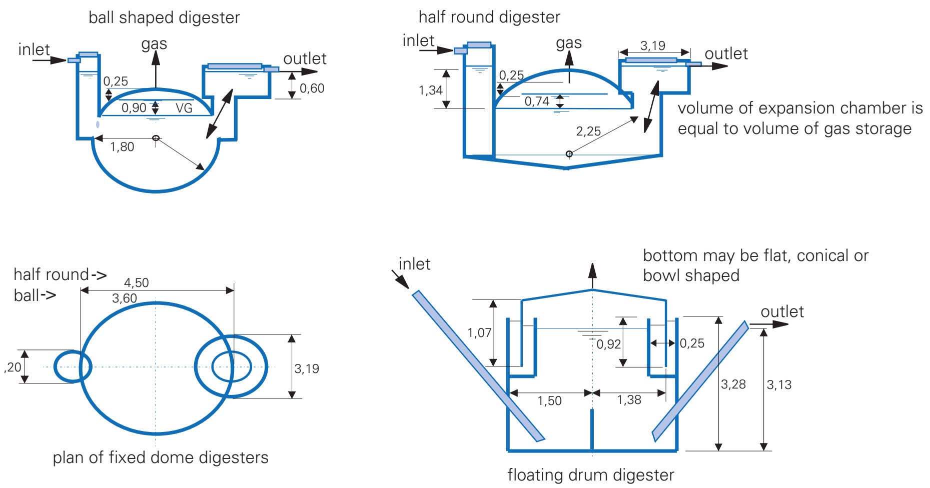
H23 = 2.09 x (G23 - 0.02) x (G23 - 0.02) x (G23 - 0.02) - E23 - H11 / 2

J23 = PI() x (I23 + I11) x (I23 + I11) x (G23 - (I23 + I11) / 3)

The volume above the lowest slurry level is found by trial and error; ϖ is expressed as PI().

K23 = E23 + H11

L23 = I23 + J11



Picture 10_20:
Illustration to spreadsheet for calculation of fully mixed digester dimensions

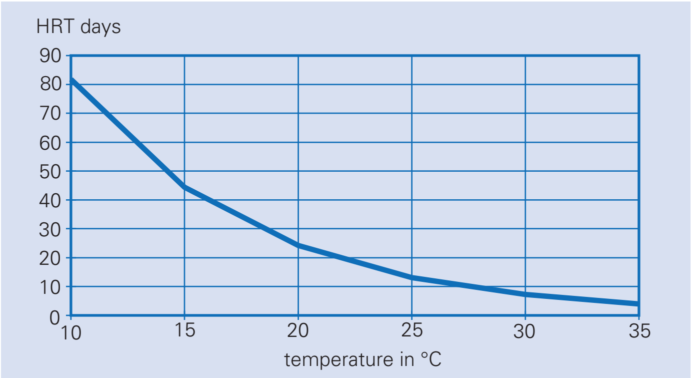
	A	B	C	D	E	F	G	H	I	J	K	L
1	General spreadsheet for biogas plants, input and gas-production data											
2	daily flow	TS (DM) content	org. DM/ total DM	org. DM content	solids settleable within one day	HRT	lowest digester tempera-ture	ideal biogas product at 30°C	gas production factors		total gas product	methane content
3	given	given	assumed	calcul.	**tested**	**chosen**	given	given	calcul. acc. to graphs		calcul.	assumed
4	m³/d	%	ratio	%	ml/l	d	°C	l/kg org DM	f-HRT	f-temp	m³/d	ratio
5	**0.60**	**6.0**	**67%**	4.0	**20**	**25**	**25**	**400**	0.97	0.90	8.42	70%
6								200 - 450				
7	values for all digester shapes									for all fixed-dome plants		
8	non-dissolv. methane prod.	approx. effluent COD	de-sludging interval	sludge volume	liquid volume	total digester volume	gas storage capacity	gas holder volume VG	free distance above slurry zero line	outlet above zero	dia-meter of left shaft	dia-meter of expans. chamber
9	assumed	calcul.	**chosen**	calcul.	calcul.	calcul.	given	calcul.	**chosen**	**chosen**	**chosen**	calcul.
10	ratio	mg/l	months	m³	m³	m³	ratio	m³	m	m	m	m
11	**80%**	7,943	**12**	4.32	15.0	19.3	**65%**	5.5	**0.25**	**0.60**	**1.20**	3.19
12										minimum 0.60 m		
13	cylindrical floating-drum plant									ball-shaped digester		
14	radius of digester	width of water ring	wall thickness of water ring	radius of gas holder	theor. height of gas holder	theor. depths of digester	actual heigh- of gas holder	actual depth of digester	volume of empty space above zero line	radius ball shape	actual digester radius (ball)	actual net volu-me of digester
14	chosen	chosen	chosen	calcul.	calcul.	calcul.	calcul.	calcul.	calcul.	**requir.**	**chosen**	**check**
16	m	m	m	m	m	m	m	m	m³	m	m	m³
17	**1.50**	**0.25**	**0.12**	1.38	0.92	3.13	1.07	3.28	0.34	1.77	**1.80**	20.56
18												
19	ball shaped digester				half-ball shaped digester							
20	lowest slurry level below zero line (fill in trial until "calcul." match "target")			gas pressure ball shaped	volume of empty space above zero line	radius half round shape	actual digester radius (half round)	actual net volume of diges-ter	lowest slurry level below zero line (fill in trial until "calcul." match "target")			gas pressure half-ball
21	**trial!!**	calcul.	**target**	calcul.	calcul.	**requir.**	**chosen**	**check**	**trial!!**	calcul.	**target**	calcul.
22	m	m³	m³	m w.c.	m³	m	m	m³	m	m³	m³	m w.c.
23	**0.90**	5.89	5.81	1.50	0.43	2.23	**2.25**	20.01	**0.74**	5.91	5.90	1.34
24				1,50 max.								1.50 max.

Table 29:
Spreadsheet for calculating fully mixed digester dimensions

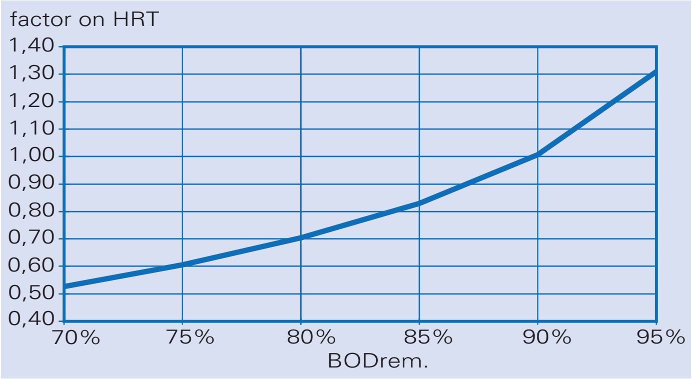
10.2.8 Gravel filter

Average flow and pollution load are the basic entries for calculation. The "chosen" parameter for the design of gravel filters is the desired effluent quality (BODout, cell E5). The hydraulic retention time and temperature have the greatest influence on treatment performance. The HRT depends on the desired BOD-removal rate (Picture 10_22); the curve is based on 25°C and 35% pore space. The pore space inside the filter defines the "real" HRT, also influenced by the type and number of plants chosen. Further influencing factors are close to 1.0; the information needed to define these factors probably not available at the site anyway.

In practice, the limiting factors are the organic load and the hydraulic load. The limit for hydraulic loading is approximately 100 l/m² or 0.1 m, although this value can be much higher when using coarse-filter media with guaranteed conductivity. A horizontal filter should not receive more than 10 g BOD/(m²xd) because oxygen supply via the surface is limited; this value is only half of the limit for aerobic ponds. This is because a gravel filter works more like a plug flow system; the organic load is much higher in the front section compared to the rear, while oxygen supply is also inferior in the lower part. As a result, the cross-sectional area at the inflow side is influenced by organic loading (cell E12).



Picture 10_21:
HRT relative to temperature in gravel filters, based on 90% BOD-removal



Picture 10_22: Influence of desired BOD removal rates on HRT of gravel filters, based on 35% pore space at 25°C

Formulas of spreadsheet "gravel filter"

D5 = B5 / C5

F5 = 1 - E5 / C5

G5 = F5 / G6

H5 = B5 x (1-G5)

J5 = IF (F5 < 0.4); (F5 x 0.22) / 0.4); IF (F5 < 0,75; (F5 - 0.4) x 31 / 35 + 0.22;
IF (F5 < 0,8; (F5 - 0.75) x 9.5 / 5 + 0.605; IF (F5 < 0.85; (F5 - 0.8) x 12.5 / 5 + 0.7;
IF (F5 < 0.9; (F5 - 0.85) x 17.5 / 5 + 0.825; (F5 - 0.9) x 30 / 5 + 1)))))

The formula refers to Picture 10_22.

K5 = J5 x IF (I5 < 15;82 - (I5 - 10) x 37 / 5; IF (I5 < 20; 45 - (I5 - 15) x 31 / 5;
IF (I5 < 25; 24 - (I5 - 20) x 11 / 5; IF (I5 < 30; 13 - (I5 - 25) x 6 / 5; 7))))

The formula refers to Picture 10_21.

G6 = IF (F5 < 0,5; 1.06; IF (F5 < 0.75; (F5 -0,5)x0.065/0.25+1.06;
IF(F5<0.85;1.125-(F5-0.75)x0.1/0.1;1.025)))

The formula refers to Picture 10_3.

L6 = L5 / 86400

A11 = K5 x 35%

D11 = IF (A5 / L5 / B11 < A5 x C5 / E12; A5 x C5 / E12; A5 / L5 / B11)

The formula compares hydraulic load to maximum organic load in cell E12.

E11 = D11 / C11

F11 = IF (A5 x C5 /L12 > A5 x K5 / C11; A5 x C5 /L12; A5 x K5 / C11)

The formula compares permitted hydraulic load with organic load in cell L12.

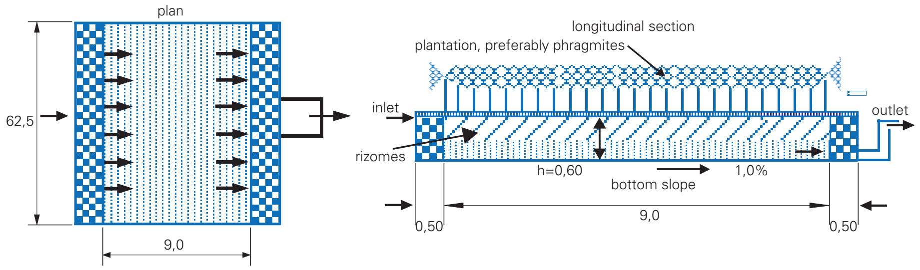
G11 = F11 / E11

J11 = H11 x I11

K11 = A5 / J11

L11 = K11 x C5

H12 = E11



10_23: Illustration to spreadsheet for calculating dimensions horizontal gravel filter

	A	B	C	D	E	F	G	H	I	J	K	L
1	General spreadsheet for planted gravel filter, input and treatment data											
2	average flow	COD in	BOD_5 in	COD/ BOD ratio	outflow BOD_5	BOD_5 removal rate	COD removal	COD out	min. annual Temp.	HRT factor acc. to k20=0,3	HRT	hydraulic conduct. Ks
3	given	given	given	calcul.	wanted	calcul.	calcul.	calcul.	given	calcul. via graph	calcul.	given
4	m³/d	mg/l	mg/l	mg/l	mg/l	%	%	mg/l	°C		days	m/d
5	**26**	**410**	**215**	1,91	**30**	86%	84	66	**25**	0,86	11,20	**200**
6			COD/ BOD rem. factor via graph ->				1,025			Ks in m/s ->		2,31E - 0,3
7	dimensions									results		
8	HRT in 35% pore space	bottom slope	depth of filter at inlet	cross section area	width of filter basin	surface area required	length of filter basin	chosen width	lenght chosen	actual surface area chosen	hydr. load on chosen surface	org. load on chosen surface
9	calcul.	chosen	chosen	calcul.	calcul.	calcul.	calcul.	chosen	chosen	**check!**	calcul.	calcul.
10	days	%	m	m²	m	m²	m	m	m	m²	m/d	g/m² BOD
11	3,92	**1,0%**	**0,60**	37,27	62,1	559	9,0	**62,5**	**9,0**	563	0,046	9,9
	^ information only		0,3 - 0,6 m	max. BOD_5 150 g/m²			always -> 62,1		max. loads =>		0,100	10

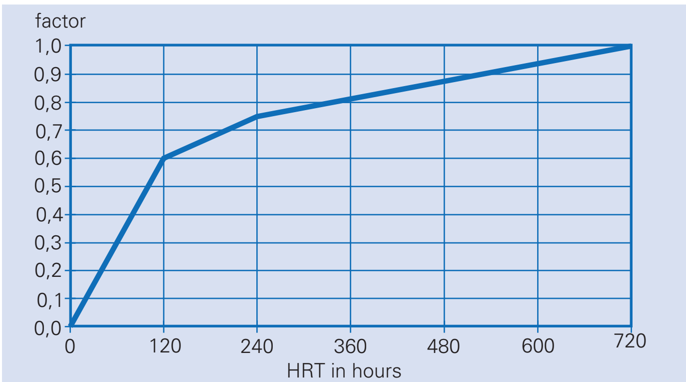
Table 30:
Spreadsheet for calculating dimensions horizontal gravel filters

10.2.9 Anaerobic pond

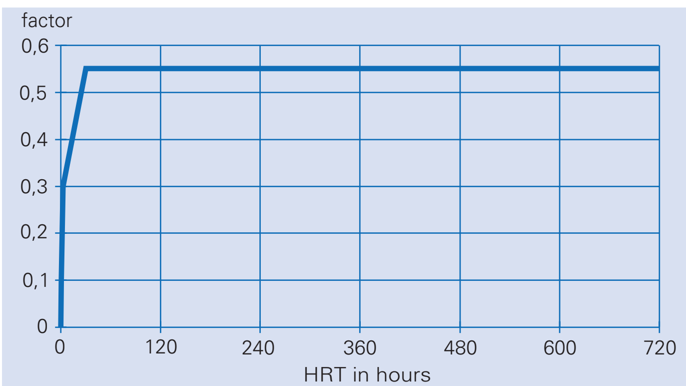
Anaerobic ponds should be built for sedimentation purposes only, as highly loaded ponds with very short retention times and heavy scum formation on the surface – or as relatively low-loaded ponds which are almost odourless because of neutral pH values. The spreadsheet may be used for all three categories. The hydraulic retention time is, therefore, the "chosen" parameter. Ponds with long retention times (low organic loading rates) may be divided into several ponds in series. For ponds with short retention times, the front section can be separated to support development of scum. The choice of HRT strongly influences the organic load of the effluent. Ambient temperature is important and an excessively high temperature should not be chosen for want of smaller ponds. It is assumed that temperature has no influence on COD removal at short retention times of less than 30 hours.

Cell G11 should be observed and compared with F11 when the pond is near residential houses.

The biogas potential is also calculated to decide whether a closed anaerobic tank with biogas collection should be built instead.



Picture 10_24: Influence of HRT on COD removal of non-settled solids in anaerobic ponds



Picture 10_25: Influence of HRT on COD removal of settled solids in anaerobic ponds

Picture 10_26: Illustration to spreadsheet for calculating dimensions of anaerobic ponds (figures of Table 31)

Formulas of spreadsheet "anaerobic and sedimentation pond"

```
D5 = B5 / C5

H5 = IF (E5 < 1; F5 / 0.6x (0.3 x E5); IF (E5 < 3; F5 / 0.6 x (E5 - 1) x 0.1 / 2;
IF (E5 < 30; F5 / 0.6 x ((E5 - 3) x 0.15 / 27 + 0,4);
IF(E5 < 120; E5 x 0.5 x (1 - 0.55 x F5 / 0.6) / 120 + 0.55 x F5 / 0.6;
IF (E5 < 240; (E5 - 120) x 0.25 x (1 - 0.55 x F5 / 0.6) / 120 + 0.5 x (1 - 0.55 x F5 / 0.6) + 0.55 x F5 / 0.6;
IF (E5 < 480; (E5 - 240) x 0,19 x (1 - 0.55 x F5 / 0.6) / 240 + 0.55 x F5 / 0.6 + 0.75 x (10.55 x F5 / 0.6);
(E5 - 480) x 0.06 x (1 - 0.55 x F5 / 0.6) / 240 + 0.55 x F5 / 0.6 + 0.94 x (1 - 0.55 x F5 / 0.6)))))))
```

The formula refers to Picture 10_24 and Picture 10_25. Below 30 hours HRT, COD removal is influenced by settling properties (F5/0.6); longer retention times also influence non-settled solids.

```
I5 = IF (E5 < 30; 1; IF (G5 < 20; (G5 - 10) x 0.39 / 20 + 0.47;
IF(G5<25; (G5 - 20) x 0.14 / 5 + 0.86; IF(G5 < 30; (G5 - 25) x 0.08 / 5 + 1; 1.1))))
```

The formula refers to Picture 10_10. COD removal by sedimentation (HRT <30 hours) is not fluenced by temperature.

```
J5 = IF (E5 < 24; 1; IF (F17 = 1;1; IF (F17 = 2; 1.08; IF (F17 = 3; 1.12; 1.13))))

A11 = IF (H5 x I5 x J5 <0.98; H5 x I5 x J5; 0.98)

B11 = IF (A11 < 0.5; 1,06; IF (A11 < 0.75; (A11 - 0.5) x 0.065 / 0.25 + 1.06;
IF (A11 < 0.85; 1.125 - (A11 -0.75) x 0.1 / 0.1; 1.025)))
```

The formula refers to Picture 10_3.

```
C11 = A11 / B11

D11 = B5 - (C11 x B5)

E11 = C5 - (A11 x C5)

F11 = A5 x C5 / (A17 + J11)

G11 = 75% x IF (G5 < 10; 100; IF (G5 < 20; G5 x 20 - 100; IF(G5 < 25; G5 x 10 + 100; 350)))
```

The formula refers to the rule of thumb by Mara, reflected in Table 22.

```
I11 = 0.005 x IF (H11 < 36; 1 - H11 x 0.014;
IF (H11 < 120; 0.5 - (H11 - 36) x 0.002; 1/3))
```

The formula refers to Picture 10_5.

```
J11 = 30 x A5 x (C5 - E11) x I11 x H11 / 1000

A17 = A5 / 24 x E5

C17 = (J11 + A17) / B17

E17 = C17 / D17

G17 = E17 / F17

J17 = A5 x (B5 - D11) x 0.35 / 1000 / H17 x I17
```

The formula assumes 350 l methane production per kg COD removed.

	A	B	C	D	E	F	G	H	I	J
1	General spreadsheet for anaerobic and sedimentation ponds									
2	daily flow	COD in	BOD_5 in	COD/ BOD_5	HRT	settleable SS/COD ratio	ambient temp. °C	BOD_5 removal factors		
3	given	given	given	calcul.	chosen	given	given	calculated acc. to graphs		
4	m³/day	mg/l	mg/l	ratio	h	mg/l	°C	f-HRT	f-temp	f-number
5	**260**	**2000**	**850**	2.35	**72**	**0.42**	**25**	57%	100%	100 %
6	domestic -> 0.35 - 0.45									
7	treatment data									
8	BOD_5 removal rate	BOD/COD removal	COD removal rate	COD out	BOD_5 out	org. load BOD_5 on total vol.	odourless limit of org. load	deslud-ging interval	sludge accum.	sludge volume
9	calcul.	calcul.	calcul.	calcul.	calcul.	calcul.	calcul.	chosen	calcul.	calcul.
10	%	factor	%	mg/l	mg/l	g/m³*d	g/m³*d	months	l/g BOD	m³
11	57	1.08	53	943	366	171	263	**60**	0.0023	512
12										
13	dimensions							biogas potential		
14	water volume	depth of pond	total area of pond	width of ponds	total length of pond	number of ponds	length of each pond if equal	methan content	non-dissolv. methane prod.	potential biogas product.
15	calcul.	chosen	required	chosen	calcul.	chosen	calcul.	assumed	assumed	calcul.
16	m³	m	m²	m	m	number	m	ratio	ratio	m³/d
17	780	**2.0**	646	**6.00**	107.67	**1**	107.67	70%	50%	68.67
18										

Table 31:
Spreadsheet for calculating of dimensions for anaerobic sedimentation pond (with short HRT). In the example, the pond is extremely long and narrow to facilitate the development of scum in the highly loaded front portion. A partition wall in the front third supports the effect. the pond was squarer, there would be no highly loaded areas, but also no sealing-scum layer. Both options are possible.

	A	B	C	D	E	F	G	H	I	J
1	General spreadsheet for anaerobic and sedimentation ponds									
2	daily flow	COD in	BOD_5 in	COD/ BOD_5	HRT	settleable SS/COD ratio	ambient temp. °C	BOD_5 removal factors		
3	given	given	given	calcul.	chosen	given	given	calculated acc. to graphs		
4	m³/day	mg/l	mg/l	ratio	h	mg/l	°C	f-HRT	f-temp	f-number
5	**260**	**2000**	**850**	2.35	**480**	**0.42**	**25**	92%	100%	108 %
6	domestic -> 0.35 - 0.45									
7	treatment data									
8	BOD_5 removal rate	BOD/COD removal	COD removal rate	COD out	BOD_5 out	org. load BOD_5 on total vol.	odourless limit of org. load	desludging interval	sludge accum.	sludge volume
9	calcul.	calcul.	calcul.	calcul.	calcul.	calcul.	calcul.	chosen	calcul.	calcul.
10	%	factor	%	mg/l	mg/l	g/m³*d	g/m³*d	months	l/g BOD	m³
11	98%	1.03	96	88	17	36	263	**60**	0.0023	881
12										
13	dimensions							biogas potential		
14	water volume	depth of pond	total area of pond	width of ponds	total length of pond	number of ponds	length of each pond if equal	methane content	non-dissolv. methane prod.	potential biogas product.
15	calcul.	chosen	required	chosen	calcul.	chosen	calcul.	assumed	assumed	calcul.
16	m³	m	m²	m	m	number	m	ratio	ratio	m³/d
17	5.200	**2.5**	2.432	**20.00**	212.62	**2**	60.81	70%	50%	124.29
18										

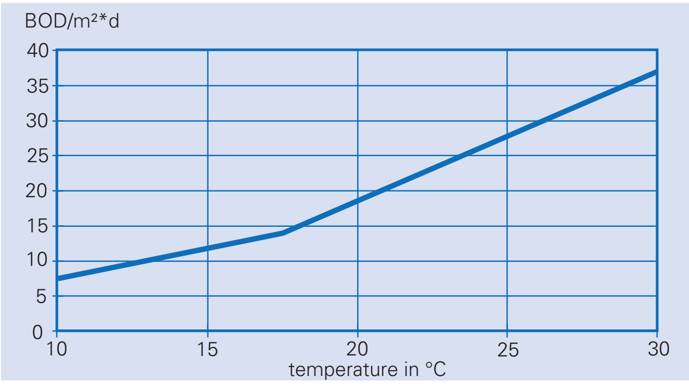
Table 32:
Spreadsheet is the same as Table 31,
ut it used to calculating of dimensions of
anaerobic-fermentation pond (long HRT)

10.2.10 Aerobic pond

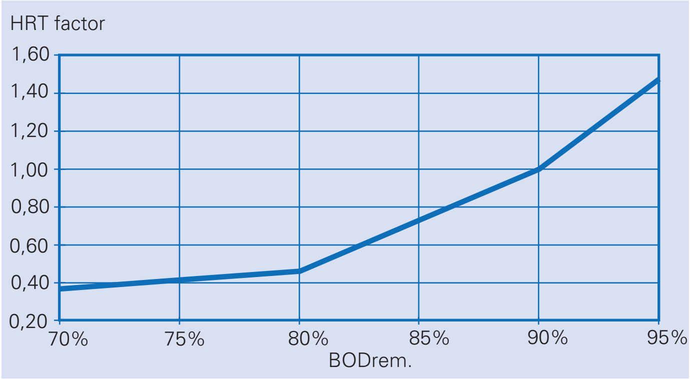
Volume of flow and pollution load are the basic entries for calculation. Key "chosen" parameter is the desired effluent quality (BODout, cell F5). The HRT required to achieve a certain BOD-removal rate depends on the temperature. The curve (Picture 10_29) shows this relationship for a 90% BOD-removal rate.

Picture 10_28 shows how HRT changes with altering treatment performance, defined as BOD-removal rate at 25°C.

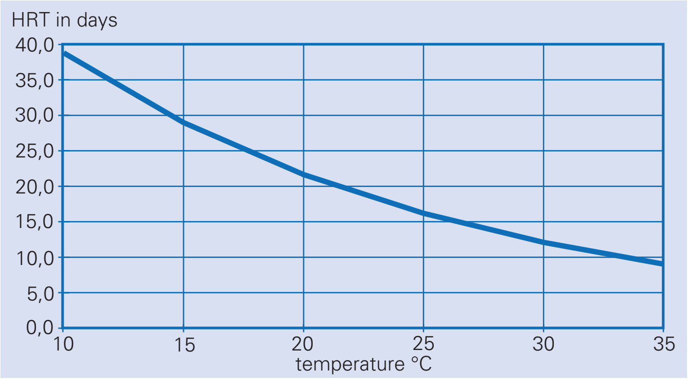
Sludge production may be high in aerobic ponds, due to dead algae sinking to the bottom. According to Suwarnarat 1.44 g TS can be expected from 1 g BOD_5. Assuming a 20% total-solids content in compressed bottom sludge and a 50% reduction of volume due to anaerobic stabilisation, almost 4 mm of bottom sludge per gram $BOD_5/m^2 \times d$ organic load would accumulate during one year. At loading rates of 15 g $BOD_5/m^2 \times d$, approximately 6 cm of sludge is expected per year. Since the surface area plays the major role for dimensioning, the sludge volume has been neglected in the calculation.



Picture 10_27:
Maximum organic load in relation to temperature for aerobic-facultative oxidation ponds; the influence of sunshine hours has been included



Picture 10_28
Influence of desired BOD removal on HRT in aerobic-facultative ponds, based on 25°C



Picture 10_29:
Influence of temperature on BOD removal in aerobic-facultative ponds, based on desired BOD removal of 90%

Formulas of spreadsheet for calculation of "aerobic pond"

```
D5 = B5 / C5

G5 = 1 - (F5 / C5)

H5 = G5 x 1 / IF (G5 < 0,5; 1.06; IF (G5 < 0.75; (G5 - 0.5) x 0.065 / 0.25 +1.06;
IF (G5 < 0.85; 1,125 - (G5 - 0.75) x 0.1 / 0.1; 1.025)))
```

The formula refers to Picture 10_3.

```
I5 = B5 - H5 x B5

J5 = IF (G5 < 0,8; (G5 - 0.7) x 0.05 / 0.1 + 0.37; IF (G5 < 0,9; (G5 - 0.8) x 0.54 / 0.1 + 0.46;
(G5 - 0.9) x 0.48 / 0.05 + 1))
```

The formula refers to Picture 10_28.

```
K5 = J5 x IF (E5 < 15; 39 - (E5 - 10) x 10 / 5; IF (E5 < 20; 29 - (E5 - 15) x 7/5;
IF (E5 < 25; 22 - (E5 - 20) x 6 / 5; IF (E5 < 30; 16 - (E5 - 25) x 4 / 5; 12))))
```

The formula refers to Picture 10_29.

```
A11 = 30 x A5 x (C5 - F5) x A12 x L5 / 1000

B11 = IF (E5 < 17; (E5 - 10) x 7.5 / 7.5 + 7.5; (E5 - 17) x 23 / 13 + 14)
```

The formula refers to Picture 10_27.

```
C11 = A5 x C5 / (F11 x G11 x H11)

E11 = IF (IF (F11 = 1; 1; IF (F11 = 2; 1 / 1.1;
IF (F11 = 3; 1 / 1.14; 1 / 1.16))) x (A11 + A5 x K5) / D11 > C5 x A5 / B11; IF (F11 = 1; 1;
IF (F11 = 2; 1 / 1.1;  IF (F11 = 3; 1 / 1; 14; 1/1.16))) x (A11 + A5 x K5) / D11; C5 x A5 / B11)
```

The first part of the formula considers the influence of dividing the total pond area into several ponds. The second part compares permitted organic load with calculated HRT.

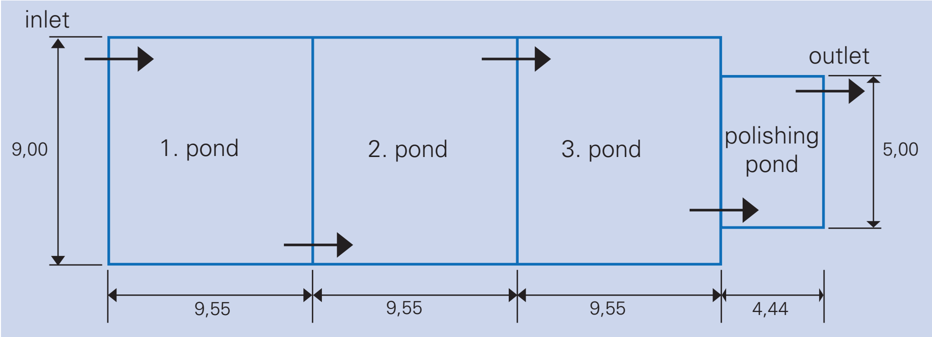
```
H11 = E11 / F11 / G11

I11 = A5 / D11

K11 = I11 / J11

L11 = I11 + F11 x E11

A12 = 0,0075 x IF (L5 < 36; 1 - L5 x 0.014; IF (L5 < 120; 0.5 - (L5 - 36) x 0.002; 1 / 3))
```



Picture 10_30: Illustration to spread sheet for the calculation of dimensions of aerobic-facultative ponds

	A	B	C	D	E	F	G	H	I	J	K	L
1	General spreadsheet on aerobic-facultative ponds, input and treatment data											
2	daily flow	COD in	BOD$_5$ in	COD/ BOD$_5$	min. water temp.	BOD$_5$ out (wanted)	BOD removal	COD removal	COD out	BOD$_5$ removal factor for HRT	HRT	de-sludging interval
3	given	given	calcul.	calcul.	given	**chosen**	calcul.	calcul.	calcul.	calcul.	calcul.	chosen
4	m³/d	mg/l	mg/l	mg/l	°C	mg/l	%	%	mg/l	%	days	months
5	**20**	**500**	**170**	2.94	**20**	**30**	82	78	108	0.59	12.9	**12**
6										0.05 - 1.0		
7	dimensions of aerobic-facultative ponds								polishing pond 1 day HRT			total
8	accum. sludge volume	permit org. load BOD$_5$	actual org. load (BOD$_5$)	depth of ponds	total pond area	number of main ponds	width of ponds	length of each ponds	area of polish pond	width of polish pond	length of polish pond	area of all ponds
9	calcul.	calcul.	calcul.	**chosen**	calcul.	**chosen**	**chosen**	calcul.	calcul.	chosen	calcul.	calcul.
10	m³	g/m²*d	g/m²*d	m	m²	No	m	m	m²	m	m	m²
11	6.3	19.3	13.2	**0.9**	258	**3**	**9.00**	9.55	22	**5.00**	4.44	796
12	0,00624	l/g BOD		0,9 - 1,2 m								

Table 33: Spreadsheet for calculating dimensions of aerobic-facultative ponds

10.3 Spreadsheets for costings

General background

This chapter helps the reader to produce his or her own tool for calculating annual DEWATS costs. Since economic calculations always incorporate the unknown future, they are never exact. However, it would be reckless to invest in DEWATS without prior economic evaluation. The spreadsheet helps jone to calculate the annual expenditure, including capital costs, operational costs and maintenance. Expected income from biogas or the sale of sludge for fertiliser may be deducted. To use the spreadsheet, the following data must be collected:

- Planning costs, including transport to site and laboratory costs for initial wastewater analysis
- Investment costs of buildings, site work and equipment
- Assumed maintenance and operating costs
- Rate of interest (minus inflation rate)
- Wastewater data to calculate possible benefits – and to compare cost per amount of treated wastewater

Formulas of spreadsheet "annual costs of DEWATS"

D5 = SUM (A5 : C5)

I5 = SUM (D5 : H5)

J5 = SUM (G9 : K9) + E13 - J13

K5 = SUM (H9 : K9) + E13 - J13

F9 = 1 + E9

G9 = E5 x E9

H9 = (F5 + D5) x (POWER (F9; 20)) x (F9 - 1) / (POWER (F9; 20) -1)

This and the following formulas are financial standard operations;
the mathematcal expression is:

I9 = G5 x (POWER (F9; 10)) x (F9 - 1) / (POWER (F9; 10) -1)

The mathematical expression is:

J9 = H5 x (POWER (F9; 6)) x (F9 - 1) / (POWER (F9; 6) -1)

The mathematical expression is:

K9 = SUM (G9 : J9) + E13 - J13

E13 = A13 + B13 + C13 + D13

F13 = A9 x (B9 -D9) x 0.35 x 0.5 / 0.7 / 1000

The formula assumes 350 l produced biogas per kg COD removed.

H13 = F13 x 70% x G13 x 0.85 x 360

J13 = H13 + I13

1	Calculating of annual costs of DEWATS										
2	planning and site supervision cost				investment cost					total annual cost	
	A	B	C	D	E	F	G	H	I	J	K
3	salaries for planning and supervision	transport and allowance for visiting or staying at site	cost for wastewater analysis	total planning cost includ. overheads and acquisition	cost of plot incl. site preparation	main structures of 20 years' durability	secondary structures of 10 years' durability	equipment and parts of 6 years' durability	total investment cost (incl. land and planning)	total annual cost (including land)	total annual cost (excluding land)
4	l.c.	l.c.	l.c.	l.c.	l.c.	l.c.	l.c.	l.c.	l.c.	l.c.	l.c.
5	1.200	650	500	2.350	150.000	295.000	9.000	3.000	459.350	74.359	62.359
6	wastwater data				annual capital costs						
7	daily wastewater flow	strength of wastewater inflow	COD/BOD ratio of inflow	strength of wastewater outflow	rate of interest in % p.a. (bank rate minus inflation)	interest factor q=1+i	on investment for land	on main structures of 20 years' lifetime (incl. planning fees)	on secondary structures of 10 years' lifetime	on equipment of 6 years' lifetime	total capital costs
8	m^3/d	mg/l COD	mg/l	mg/l COD	%		l.c./year	l.c./year	l.c./year	l.c./year	l.c./year
9	20	3.000	2	450	8%	1.08	12.000	30.286	1.341	649	37.179
10	operational cost					income from biogas and other sources					explanat.
11	cost of personal for operation, mainten. and repair	cost of material for operation, mainten. and repair	cost of power (e.g. cost for pumping)	cost of treatment additives (e.g. chlorine)	total operational cost	daily biogas production (70% CH_4, 50% dissolved)	price 1 litre of kerosene (1m^3 CH_4=0,85 l kerosene)	annual income from biogas p.a.	other annual income or savings (e.g. fertiliser, fees))	total income per annum	*l.c. = local currency; mg/l = g/m³*
12	l.c./year	l.c./year	l.c./year	l.c./year	l.c./year	m^3/d	l.c./litre	l.c./year	l.c./year	l.c./year	
13	100	100	50	0	250	12.75	2.69	7.347	0	7.347	

Table 34:
Spreadsheet for the economic calculation of DEWATS (based on annual costs).

Viability of using biogas

Whether using biogas is economically viable depends on the additional investments to facilitate storage, transport and utilisation of biogas, and if these costs can be recovered by the income generated by biogas production within a reasonable time. The payback period is considered to be an adequate indicator of viability.

Formulas of spreadsheet "viability of biogas"

B4 = 6,5% x A4

For rough calculation, it is assumed that additional construction costs are 6,5% of original costs, which includes investment for making the reactor roof gas-tight, providing additional volume for gas storage, and for gas distribution and supply pipes.

D4 = 50% x C4

To guarantee permanent gas supply, additional care must be taken at the site; it is assumed that operational costs are 50% higher than without biogas use.

F4 = B4 / (E4 - D4)

Negative values show that costs will never be recovered.

	A	B	C	D	E	F
1	Economic viability of using biogas					
2	investment cost without use of biogas	additional constr. cost to facilitate use of biogas	operational cost without use of biogas	additional operational cost to use biogas	income from biogas	pay back period of additional cost
3	l.c.	l.c.	l.c./year	l.c./year	l.c./year	years
4	**307.000**	19.955	**250**	125	**3.650**	5,7

Table 35: Spreadsheet for calculating the viability of necessary measures to facilitate biogas utilisation

10.4 Using spreadsheets without a computer

Not everybody uses a computer; some may not even have access to one. But, computer formulas may also be useful to those who usually work with a pocket calculator. The following explanations are presented for them. The calculation for the septic tank (see Table 36) is a good example:

A computer table is made up of cells. The location of each cell within the table is described by columns A.....X, AA...AX, etc. and rows 1.....>1000. Each cell within the table, therefore, has an exact address. For example, the first cell in the top left corner has the address A1 (column A, row 1). In the table below, cell J10 reads m^3/d and cell D5 reads 633. Cell I11 reads 23.25; this figure is the result of a formula hidden 'under' it. On the computer, the formula appears in the headline every time one clicks on the cell. These formulas can also be applied without a computer, in connection with the various graphs. One must realise, however, that the computer writing differs from normal mathematical writing in some points: for example, 4/(3×2) is written as =4/3/2 on the computer, and 4×2/3 may be written either 4x2/3 or 4/3x2.

	A	B	C	D	E	F	G	H	I	J
1	General spreadsheet for septic tank, input and treatment data									
2	daily waste-water flow	time of most waste-water flow	max. flow at peak hours	COD inflow	BOD_5 inflow	HRT inside tank	settleable SS/COD ratio	COD removal rate	COD outflow	BOD_5 outflow
3	given	given	calcul.	given	given	chosen	given	calcul.	calcul.	calcul.
4	m³/day	h	m³/h	mg/l	mg/l	h	mg/l	%	mg/l	mg/l
5	**13.0**	**12**	1.08	**633**	**333**	**18**	**0.42**	35	411	209
6				COD/BOD_5 ->	1.90	12 - 24	0.35 - 0.45 domestic		BOD rem. ->	1.06
7	dimensions of septic tank									
8	deslud-ging interval	inner width of septic tank	min. water depth at outlet point	inner length of first chamber		length of second chamber		volume incl. sludge	actual volume of septic tank	biogas 70% CH_4 50% dis-solved
9	chosen	chosen	chosen	requir.	chosen	requir.	chosen	requir.	check	calcul.
10	months	m	m	m	m	m	m	m³	m³	m³/d
11	**12**	**2.50**	**2.00**	3.13	**3.10**	1.56	**1.55**	23.46	23.25	0.72
12							sludge l/g BOD rem.	0,0042		

Table 36:
Sample spreadsheet used to help under-stand computer formulas

Cell A5 and all other bold written figures contain information to be collected and do not comprise formulas. The cells with hidden formulas are these:

C5 = A5 / B5

Meaning: 13,0 [m³/d] / 12 [hours] = 1,08 [m³/hours]

H5 = G5 / 0.6 x IF (F5 < 1; F5 x 0.3; IF (F5 < 3; (F5 - 1) x 0.1 / 2 + 0.3;
IF (F5 < 30; (F5 - 3) x 0.15 / 27 + 0.4; 0.55)))

Meaning: (0.42 [mg/l / mg/l] / 0.6 [a given factor found by experience]) multiplied by the value taken from Picture 10_6 at 18 hours HRT (shown in cell F5).

The calculation is, therefore:

(0.42 / 0.6) × 0.495 = 0.35 = 35% (which is shown in cell H5)

I5 = (1 - H5) x D5
(1 - 0.35) × 633 = 411 (shown in cell I5)

J5 = (1 - H5 x J6) x E5
(1 - 0.35 × 1.06) × 333

E6 = D5 / E5
633 / 333 = 1,90

J6 = IF (H5 < 0,5; 1.06; IF (H5 < 0.75; (H5 - 0.5) x 0.065 / 0.25 + 1.06;
IF (H5 < 0.85; 1.125 - (H5 - 0.75) x 0.1 / 0.1; 1.025)))

This formula refers to Picture 10_3. Since cell H5 (the removal rate) is 35%, the value of cell J6 is found in the graph and equals 1,06.

D11 = 2/3 x H11 / B11 / C11
((2/3) × 23.46) / (2.50 × 2.00) = 3.13

F11 = D11 / 2
3.13 / 2 = 1.56

H11 = IF (H12 x (E5 - J5) / 1000 x A11 x 30 x A5 + C5 x F5 < 2 x A5 x F5 / 24; 2 x A5 x F5 / 24; H12 x (E5 - J5) / 1000 x A11 x 30 x A5 + C5 x F5) + 0,2 x B11 x E11

The formula refers via cell H12 to Picture 10_5; cell H12 must be calculated first. The formula H11 states that the total volume must be at least twice the sludge volume. One has to check whether the total volume must be calculated via the hydraulic retention time or via the double sludge volume.

The total volume equals the sludge volume, which is 0.0042 × (333 - 209) × 12 ×30 [days/month] x 13.0 / 1000, plus the volume of water, which is 1.08 × 18 = 21.88 m³. This is compared to 2 × 13.0 × 18 / 24 [hours/day], which equals 19.50 m³. Since 21.88 is the larger of the two, it must be used. Finally, the volume of 20 cm of scum must be added, which is 0.2 × 2.50 × 3.10 = 1,55. The total volume is 21.88 + 1.55 =23.43 (the computer is slightly more exact and states 23,46 m³ in cell H11.

I11 = (E11 + G11) x C11 x B11
(3.10 + 1.55) × 2,00 × 2,50 = 23.25 m³

J11 = (D5 - I5) x A5 x 0.35 / 1000 / 0.7 x 0.5
(633 - 411) × 13.0 × 0.35 × 0.5 / (1000 × 0.7) = 0.72 m³

H12 = 0.005 x IF (A11 < 36; 1 - A11 x 0.014; IF (A11 < 120; 0.5 - (A11 - 36) x 0.002; 1/3))

The last formula refers to Picture 10_5. The desludging interval is 12 months (cell A11), which results in a value of approximately 80% in the graph; this figure is multiplied by the sludge-production figure of 0,005.

The calculation is, therefore:

0,8 × 0,005 = 0.004 (the computer calculates 0.0042).

Geometric formulas		
rectangle	$A = a \times b$	
rectangular prism	$A = 2x\ (a \times b + a \times c + b \times c)$	$V = a \times b \times c$
trapezium	$A = \frac{a+c}{2} \times h$	
trapeziform prism		$V = \frac{h}{3} \times h\ (a \times b + c \times d + \sqrt{a \times b \times c \times d})$
circle	$A = \pi \times r^2$	$C = 2 \times \pi \times r$
cylinder	A (mantle) $= 2 \times \pi \times r \times h$	$V = \pi \times r^2 \times h$
sphere (ball)	$A = 4 \times \pi \times r^2$	$V = \frac{4}{3} \times \pi \times r^3$
spherical segment	$A = 2 \times \pi \times r \times h$	$V = \pi \times h^2 \times (r - \frac{h}{3})$
cone	A (mantle) $= \pi \times r \times s$	$V = \pi \times r^2 \times \frac{h}{3}$
law of pythagoras	$a^2 + b^2 = c^2$	sides of 90° triangle: 3 / 4 / 5
tangent	a / b	tan 45° = 1
		tan 30° = 0.577
		tan 60° = 1.732

Table 37:
Geometric formulas

	A	B	C	D	E	F	G	H	I
1	Energy requirement and cost of pumping								
2	flow rate	main flow h/d	flow rate per hour	pump high	assumed head loss	efficiency of pump	required power of pump	cost of energy	annual energy cost
3	m^3/d	h	m^3/h	m	m	η	kw	ECU/kWh	ECU
4	**26**	**10**	2.6	**10**	**3**	**0.5**	0.18	**0.15**	100.85

Table 38:
Energy requirement and cost of pumping

Formulas of spreadsheet for "cost of pumping"

C4 = A4 / B4

G4 = 9,81 x (D4 + E4) x C4 / F4 / 3600

I4 = B4 x G4 x 365 x H

	A	B	C	D	E	F	G	H	I	J
1	Flow in partly filled round pipes									
2	pipe	flow height	flow area	moisted area/m	hydraulic radius	slope	rough ness	flow speed	flow	
3	chosen	given	calcul.	calcul.	calcul.	chosen	estimat.	calcul.	calcul.	calcul.
4	d	h/d	A	U	rhy	s	rf	v	Q	Q
5	m	m/m	m²	m	m	%		m/s	l/s	m³/h
6	**0.1**	0.15	0.00074	0.080	0.0093	**1.0%**	**0.35**	0.21	0.153	0.55
7	**0.1**	0.25	0.00154	0.105	0.0147	**1.0%**	**0.35**	0.31	0.478	1.72
8	**0.1**	0.35	0.00245	0.127	0.0194	**1.0%**	**0.35**	0.40	0.969	3.49
9	**0.1**	0.50	0.00393	0.157	0.0250	**1.0%**	**0.35**	0.49	1.932	6.96
10	**0.1**	0.75	0.00632	0.210	0.0302	**1.0%**	**0.35**	0.58	3.641	13.11

Table 39:
Flow in partly filled round pipes

Formulas of spreadsheet for "flow in partly filled pipes" (after Kutter's short formula)

C6 = 0.295 x (A6/2) ^ 2

All figures – as here 0.295 – are geometrical constants, referring to the flow height in relation to the diameter of the pipe.

D6 = 1.591 x (A6 / 2)

E6 = C6 / D6

H6 = (100 x SQRT (E6) / (G6 + SQRT (E6))) x SQRT (E6 x F6)

I6 = C6 x H6 x 1000

J6 =I6 x 3.6

C7 = 0.614 x (A7 / 2) ^ 2

D7 = 2.094 x (A7 / 2)

E7 = C7 / D7

H7 = (100 x SQRT (E7) / (G7 + SQRT (E7))) x SQRT (E7 x F7)

J8 = I8 x 3.6

C9 = 1.571 x (A9 / 2) ^2

D9 = 3.142 x (A9 / 2)

E9 = C9 / D9

H9 = (100 x SQRT (E9) / (G9 + SQRT (E9))) x SQRT (E9 x F9)

I9 = C9 x H9 x 1000

J9 = I9 x 3.6

C10 = 2.528 x (A10 / 2) ^ 2

D10 = 4.19 x (A10 / 2)

E10 = C10 / D10

H10 = (100 x SQRT (E10) / (G10 + SQRT (E10))) x SQRT (E10 x F10)

I10 = C10 x H10 x 1000

J10 = I10 x 3.6

The above graph shows the results of settling tests in a jar test under batch conditions (SS = settleable solids, TS = total solids; COD is measured as CODKMnO4). The curve might be different in through-flow settlers. The more turbulent the flow, the lesser the removal rate of settleable solids; however, BOD- and COD-removal rates increase with more complete mixing of old and new wastewater.

The performance of a domestic-wastewater settler is sufficient when the effluent contains less than 0.2 ml/l settleable sludge after a 2 h jar test.

The general formula for calculating the surface area for floatation and sedimentation tanks is:

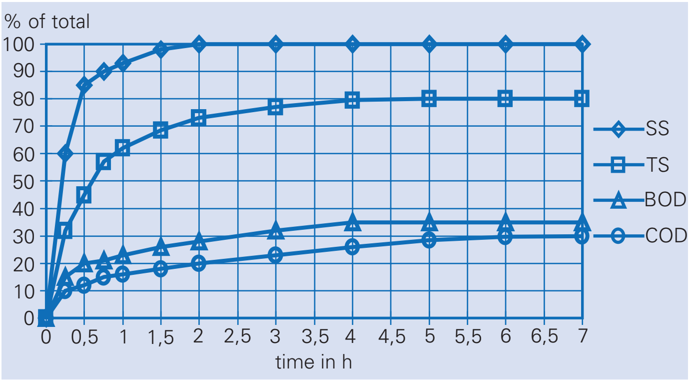
Water surface [m²] = water volume [m³/h] /
slowest settling (floatation) velocity [m/h].

Settling and floatation velocity can be calculated by observing the settling process in a glass cylinder. The formula is:

Settling (floatation) velocity [m/h] =
height of cylinder [m] / settling (floatation) time [h]

Flocculent sludge has a settling velocity between 0.5 and 3 m/h.
The velocity in a sand trap should not exceed 0.3 m/s [1000 m/h]. The minimum cross section area is then:

Area [m²] = flow [m³/s] / 0,3 [m/s], or
Area [m²] = flow [m³/h] / 1000 [m/h]



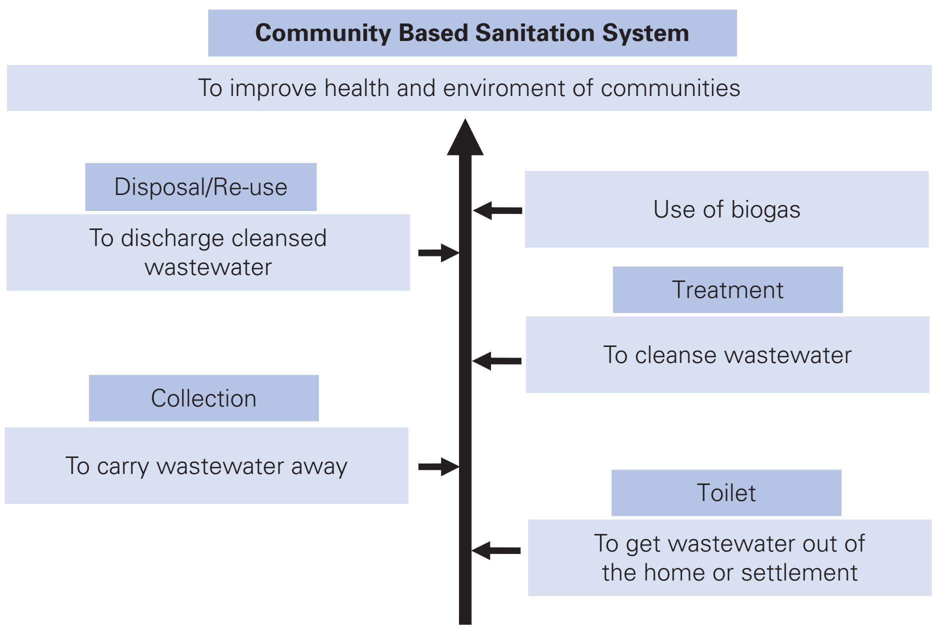
Appendix_1:
Removal rates in settling tests of domestic waste-water

11 Project components: sanitation and wastewater treatment – technical options

The other technical components of DEWATS and DEWATS/CBS systems are:

- Toilets
- Collection systems
- Sludge-disposal systems
- Biogas applications

Each component presents a wide range of possible technical options. To select the most appropriate solution for a location, the options must be assessed with the help of various criteria, such as capacity, costs, self-help compatibility, operation & maintenance, replication potential, reliability, convenience and efficiency.



Picture 11_1
Community based sanitation system

11.1 Toilets

When communities use hygiene and sanitation methods that fit their real needs and abilities, they will enjoy better health. In most cases, the toilet component is the users' prime concern. There are many reasons why users might prefer one sanitation option over another, beside, health, better water supplies or improved hygiene:

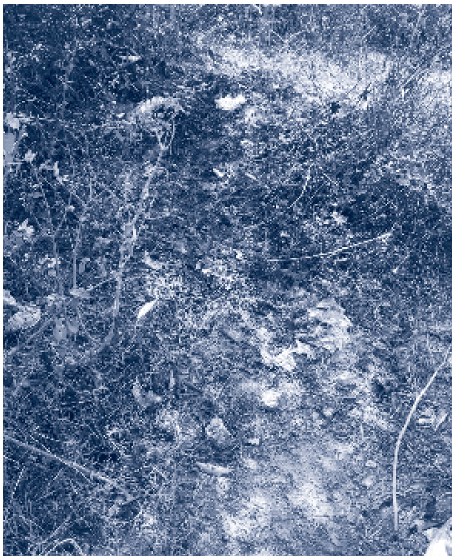
- Privacy – the need for privacy makes it important for a toilet to have a good shelter. Providing a door or enclosed entrance, or constructing it away from busy locations, makes the toilet nicer to use
- Safety – a poorly constructed toilet can be dangerous to use. If it is far from the home, women may be in danger of sexual violence. A toilet must be well-built and in a safe location
- Comfort – people prefer to use a toilet with a comfortable place to sit or squat, and a shelter large enough to stand up and move around in. Children, the elderly or people with disabilities have special needs to permit comfortable use
- Cleanliness – no one wants to use a dirty and smelly toilet. Toilet areas should be well-lit and ventilated. Easy-to-clean surfaces and cleary defined of cleaning responsibilities help to ensure that toilets are well-kept
- Respect – a well-kept toilet brings status and respect to its owner; this may be an important reason for people to spend money and effort to build one

The following section describes a selection of possible toilets – from common, hazardous models to recommended options. No one toilet design is right for every community or household. It is important, therefore, to understand the benefits and risks of each.

11.1.1 Common practices to be discouraged

Open defecation

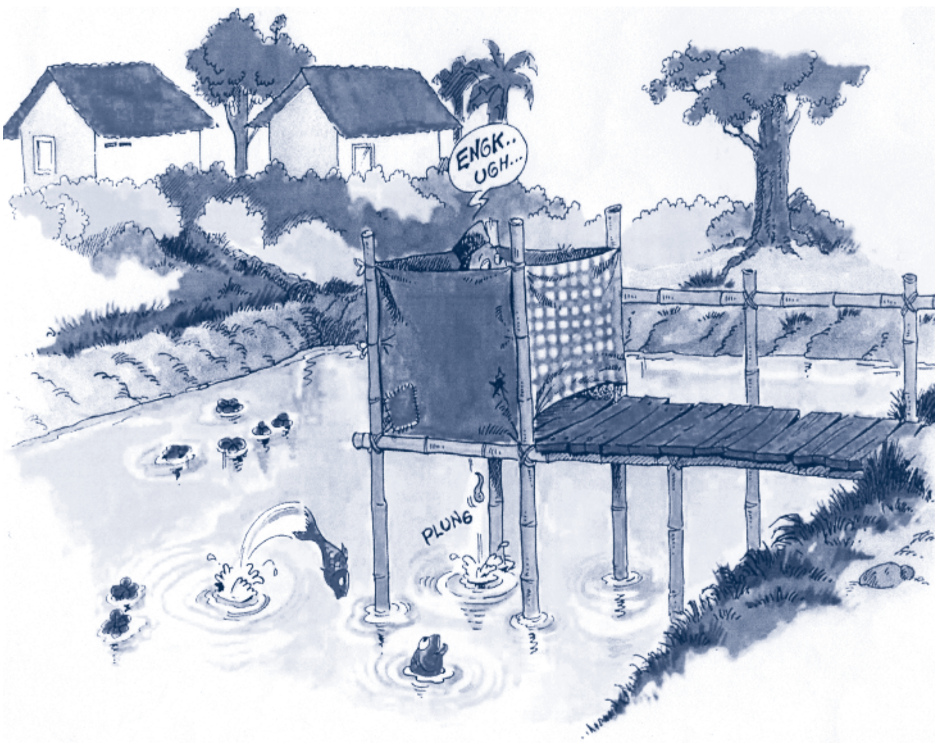
The lacking of sanitation facilities forces large parts of the world's population to defecate openly. Depending on the location, refuge is sought in the forest, jungle, lakes, rivers or the ocean. Apart from lacking privacy and the obvious associated hygienic health risks, open defecation places humans in a vulnerable situation. Women and children can easily become targets of sexual abuse or violence. In many cases, parents also worry about the safety of their children, because of poisonous snakes or other potential dangers in the bush or jungle.



Picture 11_2 and 11_3:: Residents returning from distant open-defecation areas; a bush toilet

Overhang latrine

Overhung latrines are usually built from bamboo or wood and sited above the surface of water bodies (such as rivers, ponds or lakes). Excreta fall directly into the water, where they are decomposed. Usually it is a public facility, which serves an entire or part of a community. This type of latrine pollutes the receiving water body, which can no longer be used as a fresh-water source (exceptions may include very rural settings with large or fast-moving water bodies). Furthermore, the system is usually inconvenient, as it is located away from settlements. The exposed location affords users with little privacy.



Picture 11_4: Overhang latrine

11.1.2 Closed pit toilets

Closed pit toilets are very common in developing countries and are always located outside the house.

They consist of a deep pit, which is covered by a platform with a shelter. The platform has a hole in it and a lid to cover the hole when it is not in use. The platform can be made of wood, concrete, or logs covered with earth. Concrete platforms help to keep water out of the pit and are very durable. A closed pit toilet should have a lining or concrete-ring beam to prevent the platform or the pit itself from collapsing. The average pit depth of 3 m is usually limited by the groundwater table or rocky underground. The underground of the latrine should be water pervious. Dry anal cleansing is advantageous to minimise water content. No sullage treatment is included.

The latrine can be used until it is filled up to half a metre below the top; its lifetime depends on the number of users and pit size. At that point, space is required for emptying for the pit – which is to be discouraged for hygienic reasons – or relocation of the toilet.

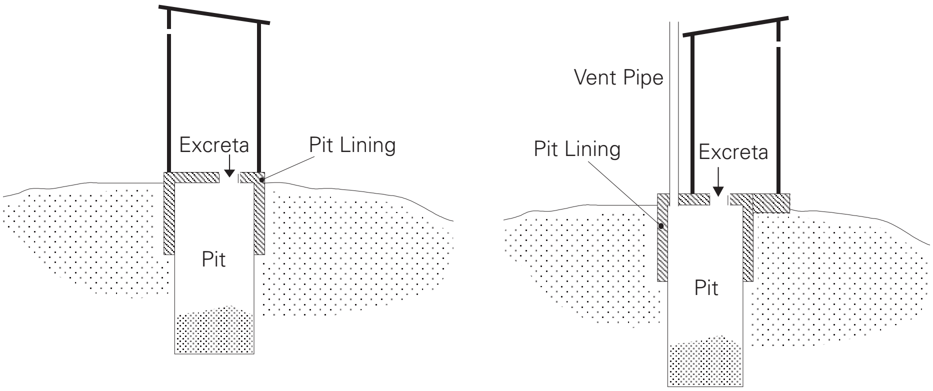
To prevent groundwater pollution and increased health risks, pit toilets are only suitable in flood-free areas, where the highest seasonal groundwater table lies well below the floor of the pit. The system has a large potential for odour, insects and hygiene hazards, especially if not cleaned regularly.

Ventilated improved pit toilets (VIP)

The VIP toilet is a kind of closed pit toilet that reduces smells and flies. The design and applicability is the same as for a normal pit latrine – made of a latrine superstructure, a pit-cover slab and a lid-covered hole for defecation. The only difference is the ventilation pipe, provided with a durable fly-screen on the top and reaching high above neighbouring roof-tops. A dark-coloured ventilation pipe should be chosen, to promote convection, or upwards air-flow within the pipe. A disadvantage of VIP latrines is that the toilet room must be kept relatively dark to encourage flies to travel towards the light at the end of the ventilation pipe, where they are trapped and die at the fly-screen. Good maintenance of the screen is important to ensure convenience and healthy conditions. Dry anal cleansing is advantageous to minimise water content. No sullage treatment is included. It is common to relocation the latrine after the pit is full.

Shallow (composting) pit toilets for tree planting

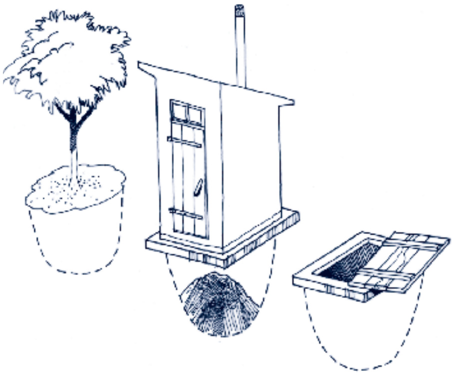
The design is similar to that of a VIP latrine – made of a latrine superstructure, a pit cover slab with ventilation pipe and a lid-covered hole for defecation. The system is better at reducing the risk of groundwater pollution when compared to other closed pit toilets because the pit is very shallow (maximum depth of 0.5 to 1 m). It thereby ensures that the faecal matter is contained within the biologically active upper soil zone, where it can be decomposed.



Picture 11_5: Standard pit and VIP latrine

When the pit fills, the toilet house, including the concrete slab, is moved to a neighbouring location and a tree is planted on the site of the first pit. Shallow pit toilets are most appropriate where there is space and people want to plant trees. They can be constructed in locations where rocky underground prevents the digging of deeper pits.

The design can be improved by installing a urine separation pan with a collection container, in sandy-soil conditions, to avoid nitrogen infiltration. The system is not suitable in areas with a rocky surface, extremely high groundwater or flooding.



Picture 11_6 to 11_9: Shallow (composting) pit toilets for tree planting. Source: Stockholm Environment Institute, 2004

11.1.3 Composting toilets

Composting toilets retain faeces and urine and turn them into soil conditioner and fertiliser. Sitting or squatting models are available.

The composting latrine consists of a squatting plate, which is placed over a watertight vault usually constructed above the soil. The vault is ventilated through a pipe, which extends above the surrounding rooftops and has a fly-screen at the top. To support the composting process it is necessary to add dry organic material, such as straw, leaves, sawdust, soil or vegetable waste, at daily intervals. This reduces smells and helps the waste to break down. Different techniques can be applied to reduce the water content, thus guaranteeing optimal aerobic conditions. Under the right conditions, the mix will heat up, thereby killing most germs, including roundworm eggs (the hardest to kill). After sufficient treatment time (usually one year), the composted material is removed for use as a fertiliser. To be safe, it is best to mix it into a compost pile, where it will break down more. Then it can be mixed into the soil for planting.

Due to the importance of the moisture content in the chamber, composting latrines are only suitable for communities using dry cleansing material or with separate wash-water drainage and treatment. Since the water content within the vault must be monitored, the users must fully understand and appreciate the process to ensure proper operation of the system without odour or insect nuisance.
The toilet is normally located outside the house and can be used for many years, if operated properly. The system is convenient in rural areas where composting is traditionally practised. No sullage treatment is included.

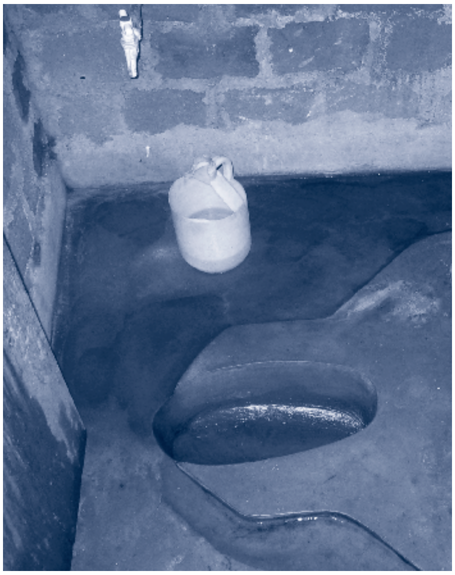
A variation of the system includes two vaults, which are alternately in use. While one vault is being used, the content of the other is topped up with 30 cm of soil and covered with a concrete slab. With time, the contents are dehydrated through evaporation and decomposed by micro-organisms. When the second pit is full, the odourless and partially disinfected compost can be removed from the first pit. If it is still wet and smells, further composting or storage in a dry place is advised. Wear gloves, and wash hands after handling the fresh fertiliser.

11.1.4 Dry, urine-diversion toilets

Dry, urine-diversion toilets combine toilet house and treatment facility into one above-ground structure. They can be located inside the house, attached to it or left as a free-standing unit in the yard. Urine and faeces are collected separately by special toilet models of various designs. Sitting and squatting models are available.

The super-structure is elevated to create sufficiently sized faeces-storage volume below the cover slab. These storage chambers are waterproofed to ensure dry conditions, even in the case of heavy rain or flooding.

The key to successful operation is the fast dehydration of the faeces. Laying bamboo, cornstalks, branches or other dry plant matter on the floor of the chamber before initial use facilitates the drying process. Furthermore, a handful of ashes, sawdust or dry soil sprinkled over the faeces after defecation will to absorb moisture and avoid fly breeding.



Picture 11_10 and 11_11: Selection of urine-diversion and, squatting toilet models

A ventilation pipe, which extends above the surrounding rooftops and has a fly-screen at the top, causes a constant draft into the toilet, thereby drying the faeces and avoiding smell. Ventilation is increased by using black chamber-access doors facing the sun.

From the separation toilets, urine can be led to collection containers. If collected, it should be treated by air-tight storage for three to six months before being diluted 10 to 1 with water and used as a liquid fertiliser rich in phosphorous and nitrogen. Alternatively, urine – together with water used for anal cleansing – can be led into an evapo-transpiration reed-bed next to the toilet house. Its plants are cut back periodically, chopped into small pieces and added to the processing vault after drying. Good experiences with the system have been reported in South India, even in conditions humid conditions. The traditional Vietnamese double-vault toilet works in the same way but only in combination with dry anal cleansing and urine utilisation for agriculture purposes.

Picture 11_12 and 11_13: Selection of urine-diversion and, squatting toilet models

Faecal storage and treatment can be practised with two possible systems:

a) Two-chamber system: the compartment below the toilet is divided into two chambers. When one chamber is full, it is closed and the second one is used. When the second is full, the first is emptied. The toilet model either has two faecal openings (one leading to each chamber), or the toilet bowl can be removed and turned around to use the other chamber.
b) Storage receptacles: the compartment below the toilet contains several containers. Plastic bins or locally produced reed-baskets can be used. When one of the containers fills, the chamber is accessed and the full container is replaced with an empty one. The full container remains in the compartment. When all storage capacity has been exhausted, the full container with the longest storage time is removed and emptied. Reed-baskets are perfect if further composting is desired.

Access to the faeces chamber can be through a water-tight door, a concrete slab or a temporary hole (weak mortar brickwork) in the chamber wall.

The system is suitable for all geographical conditions – particularly in regions with water scarcity, high groundwater table, flooding or rocky soil. Implementation requires the users to have intensive training. It is not recommended for public or communal toilets, as there is a high risk of misuse.

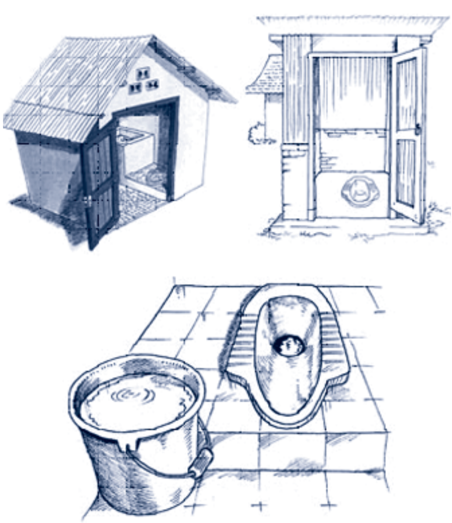
11.1.5 Pour-flush toilets

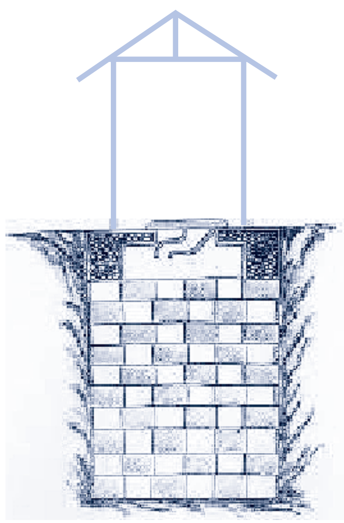
Pour-flush toilets are very common; sitting and squatting models are available. Excreta are washed away with approximately 0.5 to 2 litres of water poured into the pan with a scoop. These toilets should only be applied,therefore, where adequate amounts of flush water are available. Since they have a water seal against odours and insects, pour flush-toilets can be located within the house, if desired. Where water is required for anal cleansing, pour-flush toilets are particularly suitable because the same water can be used for flushing. As no complex mechanical devices are needed for operation, the toilets are robust and rarely require repair. Since water is available near and in the toilet, cleaning is very easy.

Pour-flush toilets use a plastic, fibreglass, or cement bowl or squatting pan set into a concrete platform. The concrete platform can either be placed directly over a pit, or it can be connected by pipe to one or two pits. Alternatively, the pipes can feed into a wastewater-collection system or directly into other treatment units (i.e. septic tank).

Pour-flush toilets with one leach pit

Single leach pits are made of a latrine superstructure and a WC pan with a water seal. A collection pipe, 100 mm in diameter, is laid at a gradient of at least 1 in 20, if the pit is off-set. The wastewater is discharged into a pit lined with water-pervious brick or stone work. Pits should be covered with reinforced-concrete slabs, stone slabs or wooden planks, secured against mischief by children.





Picture 11_14:
Pour-flush toilet

Picture 11_15:
Pour-flush toilet
with one leach pit

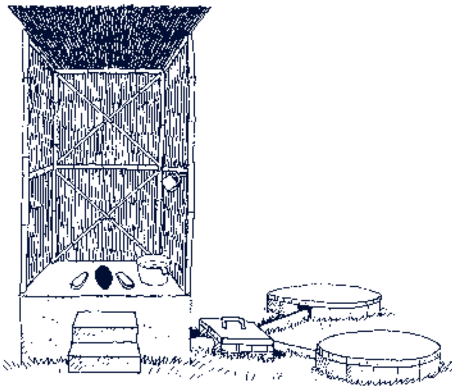
Pour-flush toilet with single leach pit

One-pit pour flush toilets can only be used until it the pit is full. A five-headed family will fill a lined pit of two metre depth and 1 meter diameter in approximately 5 years and emptying is required before continued use is possible. Desludging should be provided by professional service providers to minimise health risks. It is easier if the pit is off-set and not directly under the superstructure. Pour flush pit toilets should be applied only in flood-free areas, where the highest seasonal groundwater table lies at least 3 m below ground level.

Pour-flush toilet with two leach pits

When there are two pits, a valve directs the wastewater to the pit currently in use. The first pit is used until it is nearly full. Then waste is diverted into the second pit. Soil is added to the first pit and its contents are left to settle for at least two years, then it can be emptied without any great risk of illness from germs.

For a family of five, two pits measuring one metre deep and one metre in diameter would need alternating approximately every three years. The distance between the pits should be at least the same as the depth of the pits.
Pour flush pit toilets are only appropriate in flood-free areas, where the highest seasonal groundwater table is more than 3 m below ground level.



Picture 11_16: Pour flush toilet with two leach pits (toilet house shown without door)

Pour-flush toilet with individual septic tank and French-drain gravel filter

Pour-flush toilets can also lead the wastewater into a small on-site treatment facility. Septic tanks are watertight containers, which provide primary treatment by separating, retaining and partially digesting settleable and floatable solids in wastewater. Septic-tank effluent must receive proper secondary treatment before being discharged to the groundwater or surface water bodies. Directly ensuing soakage pits should not be applied, if the vertical distance from the bottom of the soakage pit to the highest seasonal groundwater is less than 1.5 metres. In these cases, septic tanks can be combined with French-drain filters or equivalent treatment. Septic tanks accumulate sludge which must be emptied after approximately five years and treated separately.

French-drain filters are simplified horizontal, gravel filters for on-site sanitation where there are space constraints and a high groundwater table. They provide simple filtration and anaerobic treatment, where high groundwater tables prevent direct septic-tank effluent infiltration. At the end of the French-drain filter, water is infiltrated to the soil though a plant-bed.

Picture 11_17 to 11_20: Construction of a French-drain filter, connecting a plastic septic tank with a plant-bed

Pour-flush toilet attached to wastewater-collection system

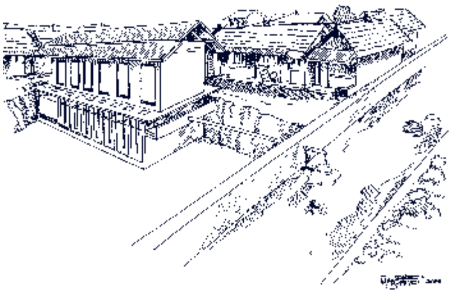
Since pour-flush toilets operate with water, the waste can be washed into a local wastewater-collection system, which transfers the excreta to a centralised or decentralised-treatment facility. For more details on wastewater-collection systems, please refer to chapter XX.

11.1.6 Community toilet blocks

Community toilet blocks usually consist of a number of toilet compartments. A large variety of available superstructure options can also include bathrooms, public water-points and laundry facilities.

Each toilet should not be shared by more than six households or 25 people. Integrated concepts can include treatment options such as septic tanks or baffled reactors. Community toilets are a suitable CBS option in settlements where the majority of the households don't have toilets. For convenience, communal toilet blocks should be no further than 50 metres walk.

Past experience has shown that maintaining and operating community toilets properly is a major obstacle for their sustainability. User fees are a "must" to finance routine operation and maintenance services, which ought to be carried out by permanent or part-time O & M staff employed by community groups or private-service providers.



Picture 11_21 and 11_22: Community toilet blocks

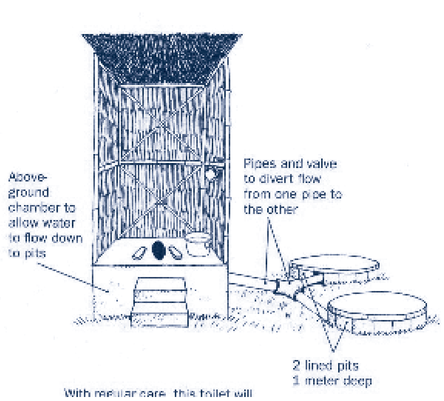
11.2 Rainwater drains

Open rainwater drains

Systems with open ditches for a discharging rainwater are quite common in the urban areas of developing countries. The ditches usually drain rainwater into rivers or, sometimes, into agricultural-irrigation canals. The unauthorised discharge of domestic waste or drainage of sullage through such a system is a health hazard and should be discouraged.

Covered rainwater drains

Covered rainwater drains are often used to collect wastewater in areas which lack conventional sewerage systems. Drains are covered by concrete slabs to stop them being blocked up by litter and to prevent people from coming in contact with their contents. So that rainwater can enter the system, periodic inlets in the drain covers are required. Theoretically, connected treatment plants would have to be designed for the purification of combined flows – rainwater and domestic wastewater – which requires a very high treatment capacity and investment. Such systems present a temporary solution, where no other system of waste-water collection is available, but it should be replaced by an improved system as soon as possible. The system smells, promotes insect breeding – and remains a health hazard.

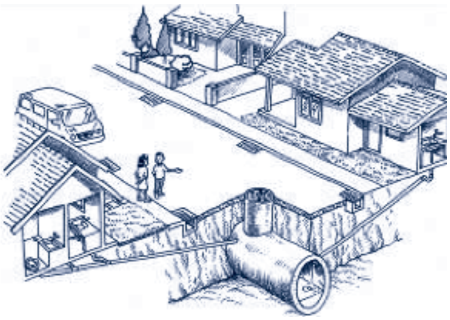


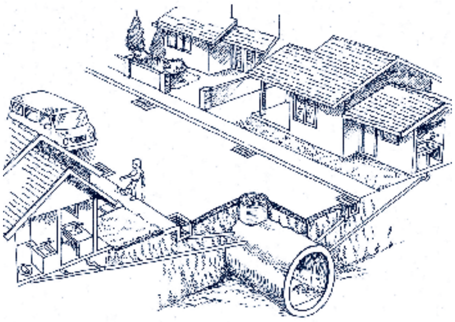
Picture 11_23 and 11_24: Open and closed rainwater drains

11.2.1 Conventional gravity sewerage

Conventional gravity sewerage

In conventional gravity sewerage, domestic wastewater flows to a treatment facility via a system of concrete pipes. The system consists of house connections, which lead to a reticulation sewer line, normally laid beneath the main roads. There are inspection along the route at least every 70 m.





Picture 11_25 and 11_26: Conventional gravity sewerage system

So that the system can be cleaned, the minimum diameter is usually 200 mm (D). To avoid solids deposit, minimum velocity of 0.5 m/s is required. The maximum velocity should not exceed 6 to 8 m/s. The necessary gradient of the pipes is, in part influenced by their diameter. In preliminary design, the gradient (IS) can be estimated through the equation IS=1/D. In flat areas, conventional sewer systems can demand very deep and expensive excavation. To avoid excessively deep sewers in large systems, it is necessary to use either a flushing tank or construct a pumping station. In Europe, pipes are usually laid at a minimum depth of 1.5 to 2.0 m to guarantee load rating suitable for normal traffic as well as frost protection.

The maintenance of the reticulation system plus the operation and maintenance of possible pumping stations make up the operating costs.

Combined gravity sewerage

In combined gravity sewerage, domestic wastewater flows to a treatment facility together with collected rainwater, in a similar system to the conventional gravity sewerage. However, since the system must be designed to handle peak flow, much bigger pipe diameters are required for the mixed flow; diameters in the range of 300 to 1.200 mm (D) are common. Furthermore, inlets for rainwater from roof and street run-off are necessary.

Just because such gravity systems are currently considered the standard solution in most developed countries, does not mean that the conventional or the combined sewerage system is the optimal solution under all conditions. Engineers should compare all feasible options on an economic and technical basis.

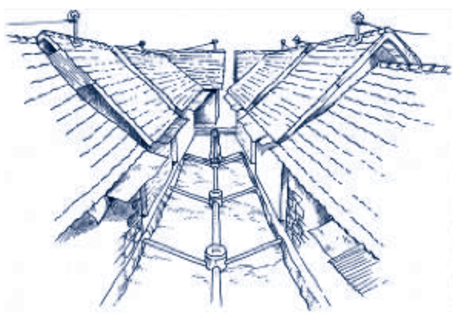
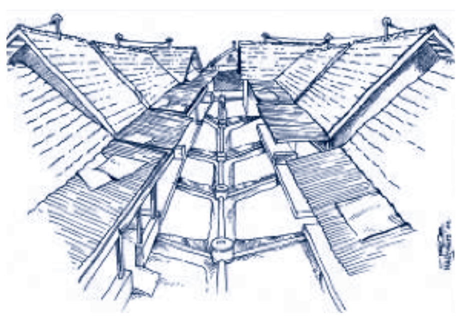
Simplified gravity sewerage

Simplified gravity-sewerage systems function like their conventional, larger counterparts. But the design criteria for construction have been simplified so that they just comply with minimum hydraulic requirements. As a result, the pipes made from plastic or concrete have smaller diameters and are usually laid at a flatter gradient and a shallower depth. The system can also cope with fewer inspection manholes. Although the costs are reduced, there is an increased probability of malfunction, resulting in more intensive operation and maintenance work.

Condominial gravity sewerage

Condominial sewerage is usually based on a PVC-piping system with a minimum diameter of 100 mm, leading wastewater towards a nearby treatment facility or towards another sewer network. Pipes are laid at a flat gradient and routed through private land, such as frontyards, backyards (in-block) or pavements. So the required tyre load capacity is considerably less than for in-road systems. Consequently, it is possible to lay the pipes at a shallow depth. Backyard and frontyard systems require a minimum cover of 20 cm, while cover under sidewalks should be 40 cm. Another advantage of backyard sewers is the reduced piping length, resulting in reduced costs. Furthermore, shallow condominial sewerage systems do not require large, expensive manholes.

Simple inspection chambers (located every 20 m) and junction boxes at sewer connection points are usually sufficient. As with all systems, who's responsible for maintenance should be clearly defined.

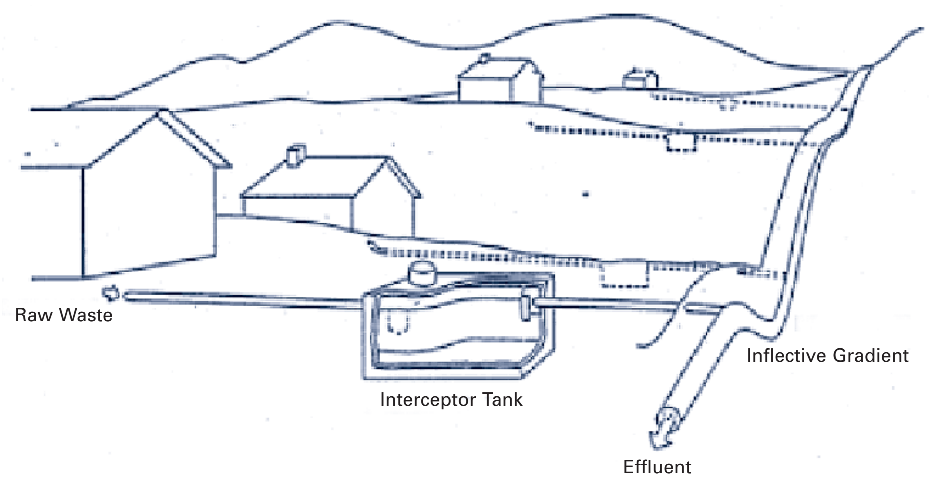



Picture 11_27 and 11_28: Backyard and front-yard condominial gravity sewerage

11.2.2 Small-bore sewerage

Small-bore systems, also called "solid-free sewers", "common effluent drains" or "settled sewerage", receive the effluent from individual or shared household septic tanks. Hence, coarse solids are removed and only the liquid part of sewage enters the sewerage system. Unlike conventional gravity systems, no self-cleansing flow-velocity is required. As a result, small-bore sewers can be operated with less water, allowing the connection of (low) flush toilets (including pour-flush) from households served by a standpipe or yard tap. The pipes have smaller diameters. Flow is driven by the elevation difference between inlet and outlet, and, therefore, can be installed very close to the surface in all types of terrain and even allow inflective gradients.

Simplified sewerage systems, the clogging and blocking of pipes is very unlikely, because of the pre-treatment in septic tanks. This effectively reduces the amount of maintenance needed on the piping system, although regular septic-tank emptying is essential.



Picture 11_29: Small-bore sewerage system

A 100 mm-diameter pipe at a slope of at least 1:60 is required to connect the toilet to the septic tank. The level of the tank should not be deeper than necessary, so that the maximum potential energy (arising from its elevation) is available for the flow in the main sewer. At the least the first two metres of the connecting pipe from the septic tank to the plot boundary should have a diameter slightly smaller (50mm diameter) than the sewer main. This reduces the risk of blockage in the main sewer. Any misuse of the tank would then result in the plot-owner being inconvenienced rather than the whole neighbourhood.

The small-bore sewer mains should consist of plastic pipe with a minimum diameter of 100 mm, installed at a depth of at least 300 mm on plots, 1 m on public lands or roads, and 1.2 m when crossing roads. Clean-out points should be located at the upstream ends of the system, at the intersection of sewer lines, at major changes of direction, high points, and intervals of 150 to 200 m in long, flat sections. These provide access to the sewer inspection and flushing during sewer cleaning. Manholes are not required.

Unlike conventional gravity sewers, small-bore sewers can alternate between open channel and pressure flow, taking maximum advantage of the elevation difference between the upstream and downstream ends of the sewer. Care must be taken that the hydraulic grade line during peak flow does not rise above the invert of the septic-tank outlets. If this is assured, the sewer may have low points or dips and can curve to avoid objects. High points of the sewer should be ventilated. As the sewer is not intended to carry solids, it is designed on hydraulic considerations only.

Pumping stations are only required where elevation differences do not permit gravity flow. If this is the case, permanent electricity supply and professional maintenance services are required for sustainable operation.

Due to the nature of the effluent from the septic tanks, the effluent of small-bore sewers is highly corrosive and odorous. If required, pumps and pump wells should be protected against corrosion and odour emission.

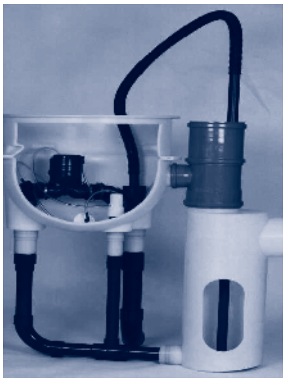
Vacuum sewerage

Vacuum wastewater-collection systems save water by using air as the main transport medium within the pipelines, by maintaining a low pressure of 0.6 bar within the sewer network with vacuum pumps. The sewerage lines can be installed very close to the surface in all types of terrain – and can even transport wastewater around obstacles and up-hill. They require a power supply at one centralised location. The system consists of three basic elements: collection chambers, sewer network and a vacuum station.

Any type of (low-)flush toilet (including pour-flush) can be used. The wastewater drains from the household to a collection chamber by gravity. These chambers are not mechanised and can be located on or near the plot, and can receive wastewater streams from several neighbouring households. When the wastewater in the collection chamber reaches a certain level, an interface valve is triggered and opens automatically without an external power supply. This valve connects the collection chamber to the low-pressure sewer network. Together with the wastewater, about six times more air will be sucked into the system. The air is used as a transport medium for the wastewater, reaching transport velocities of 4 to 6 m/s on the way to the vacuum vessel or pump sump in the vacuum station. When the collection chamber is emptied, the interface valve closes again. The pump sump is connected to a treatment facility.

Collection chambers must be made of watertight, smooth, corrosion-resistant material and big enough to take 25% of the average daily flow. The pipe network is made of PE-HD or polyvinyl chloride (PVC); both can be electro-welded or solvent-welded (cemented). Only the short gravity sewer from the house to the collection chamber must have a minimum diameter of 100 mm and be laid at 1:60 or steeper.

The minimum size of the vacuum sewer grid should be 90 mm diameter. Pipelines should be designed to withstand the internal suction pressure and temperature. The minimum pressure rating of selected pipes should be 9 bar. The minimum cover of the main vacuum pipeline under roads should be only 1 m and 1.2 m. The vacuum sewer mains and branch connections should have isolation valves ever 500 m and 200 m respectively.



Picture 11_30 to 11_32: PE-HD vacuum Pipe with individual connection (left), collection chamber (centre), waste-water collection, water supply and stormwater-drainage pipes in one trench (right)

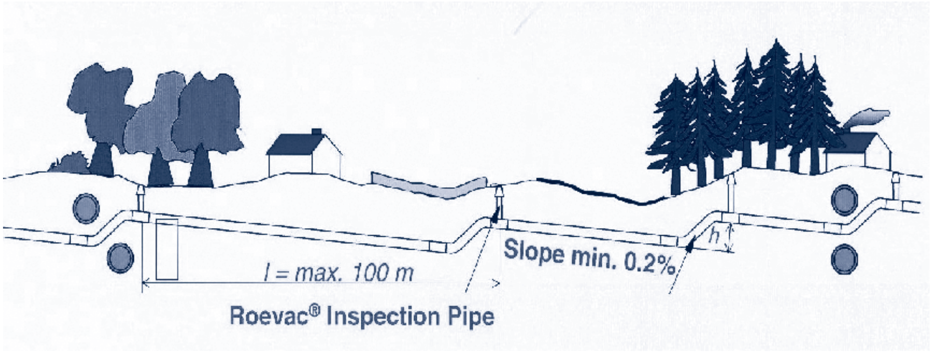
Since the flushing velocity is provided by the suction pressure, the pipelines do not require a downward slope, although they should have a minimum gradient of 1 in 500; however, the pipes can even be laid uphill. Lifts – or short, upward sections of pipe – can be used to ensure that the pipes do not have to be laid at excessive depths or to avoid objects. It is recommended that the pipe should be laid with a saw-tooth profile.

Since the whole system is watertight, it can be installed directly in the groundwater table, in flood areas or in the same trench as water-supply lines. Unlike gravity or small-bore sewer systems, vacuum sewer-pump capacities do not have to meet the peak wet-weather flow. There is no infiltration, no exfiltration and no groundwater contamination.

Routine maintenance checks of the network are not necessary, as a change in system pressure will indicate problems. Inspection pipes, installed at distances of approximately 100 m permit the insertion of inflatable balls and precise location of the problem. The vacuum station should be inspected every week, collection chambers and vacuum vessel every year and the valve diaphragm in the collection chamber needs to be changed every five years.

Because of these technical maintenance requirements and energy-supply demands, the system is not appropriate in all locations. But it can have advantages where other systems are too costly or not feasible:

- flat topography – avoiding extensive installation excavation or lifting stations
- rock layers, running sand or a high groundwater table
- areas short of water supply or poor communities that cannot afford the amount of water necessary for operating of gravity systems at scour velocities
- ecologically sensitive locations or flooding zones
- areas with obstacles to a gravity sewer route
- installation of new fresh-water network and sewerage pipes in the same trench



Picture 11_33: Design of vacuum sewer layout (saw-tooth profile). Credit: ROEVAC Manual

11.3 Sludge accumulation

All organic-degradation processes produce certain amounts of biomass or sludge, which gather at the bottom of treatment units. Sludge changes its properties with time, due to the activity of micro-organisms and the degradation of organic components. When organic degradation has been completed and all bio-chemical reactions stop, the sludge has been "stabilised". Stabilised sludge is less odorous and easier to dewater and treat.

The speed of sludge production, and the sludge's characteristics depend on the wastewater quality, sludge-retention time and other treatment parameters. Under certain conditions, there is no accumulation of sludge. A state of equilibrium between sludge production and degradation is possible in an anaerobic environment with high temperatures, adequate bacterial feed within the sludge and long sludge-retention times. Under such conditions, 80% of the organic matter is converted into biogas, while the remaining organic matter is pushed out in dissolved form as effluent. Experience at existing DEWATS facilities in tropical regions, like Indonesia, shows that well-designed and constructed anaerobic units avoid the necessity of sludge removal.

In most locations, however, such boundary conditions cannot be guaranteed and even well-designed DEWATS will accumulate sludge with time. This can be caused by cooler temperatures (particularly below 15°C) or wastewater with higher mineral content. Aerobic processes, due to the faster reproduction rate of their bacteria, produce several times more sludge than anaerobic ones.

Sludge accumulation leads to a reduction of capacity and retention time within a treatment facility, ultimately resulting in inefficient treatment and the discharge of hazardous wastewater. Neglect of regular sludge removal can lead to the sludge mineralising at the bottom of the unit, until it reaches a consistency, which makes removal impossible without an operational halt and total emptying of the facility. To ensure adequate treatment and continuous operation, therefore, sludge must be removed at appropriate intervals.[34]

Sludge from domestic and husbandry wastewater is highly contaminated by worm eggs and cysts. Practices like illegal sludge-dumping into rivers, lakes or malfunctioning treatment plants pose a risk to human health and the environment. Ensuring an infrastructure for safe removal, handling and treatment, therefore, should be an integral part of town or city planning and management. It must be considered in the planning and construction of any wastewater-treatment facility.

Sludge removal, drying, treatment, selling, reuse or disposal can either be practised directly by the operator of the wastewater-treatment facility or by a service provider.

11.3.1 Sludge removal

Sludge removal should only be practised by trained personnel, as both the sludge and the gases within the facility present dangers. Particularly in anaerobic processes, methane and H2S are produced, creating a risk of suffocation. Ventilation must be provided and open fire should be prohibited at the facility. Sludge settles in layers. The top layers contain active bacteria, which provide treatment by feeding on the wastewater, while the lower layers stabilise and become inactive with time. The goal of desludging is to remove only the older, bottom sludge; 30 to 50 cm of active sludge should remain to ensure continuous treatment efficiency.

34 Sludge should remain within the facility as long as possible, since stabilised sludge is easier to handle and dewater. At the same time, the sludge storage capacity must not be exceeded to ensure continuous treatment efficiency. Sludge removal intervals depend on the wastewater, type of treatment and storage capacity of the facility. Conventional tank design requires sludge removal every half to three years; ponds must be emptied every one to twenty years.

Desludging can be done with buckets, by pumping or by hydraulic pressure.

- Bucket removal is discouraged because it is impossible to withdraw only the lower sludge layers. Handling poses health risks to the operators. If practised, the workers should wear protective clothing by over their mouth, hands and feet
- For pumping, free-flow rotary pumps are recommended to prevent clogging. The pump head is lowered to the chamber floor to remove only the oldest sludge. The pumped effluent should be visible; when the sludge becomes too light in colour, pumping should be halted to give the sludge time to flow to the mouth of the pump. Only black, stabilised sludge should be removed
- Hydraulic desludging is practised through installed pipes at the bottom of the chamber with a diameter of at least 100 to 150 mm diameter. The ductile consistency of settled and compacted sludge requires the outlet of a 2.5 m-long pipe to be 0.35 to 0.50 m below the normal wastewater outlet, to overcome the hydraulic loss of 15 to 20%. Sludge flow is regulated with a gate valve, which has a free opening of the full diameter, or by flexible pipes, which are lowered to initiate desludging. When not in use, these flexible pipes should be closed and locked to protect against smell and insects, while valves handles should be removed to prevent children getting up to mischief.

11.3.2 Sludge treatment

The goals of sludge treatment are:
- stabilisation
- dewatering/dehydration and volume reduction
- wastewater treatment of leachate or liquids
- pathogen destruction
- agricultural reuse or environmentally safe and hygienic disposal

Unstabilised sludge should not be dried or treated openly anywhere near where people live because of bad odour and the nuisance from flies. The origin and properties of sludge, therefore, determine which treatment should be applied: sludge from grease traps, settlers or septic tanks – also called septage – contains relatively fresh waste and has a solid content below 1%. These substances should be transported to nearby centralised treatment facilities for further stabilisation before final sludge treatment. Organic industry sludge must be removed quite frequently. Treatment in anaerobic digesters is recommended, due to its high organic content and biogas potential.

Domestic DEWATS units produce small amounts of well-stabilised sludge with good dewatering properties. In urban areas, the sludge shaved be transported to an existing centralised treatment plant. Where this is not possible, two sustainable treatment and disposal options have been identified:

- Small-scale application: the stabilised sludge can be dried on sand-beds – either directly next to the DEWATS or at a more appropriate location – and eventually the sludge can be composted and turned into agriculturally valuable humus
- Large-scale application: the construction of a decentralised sludge-treatment facility with DEWATS components. This option is only financially viable, if there are enough DEWATS or on-site treatment plants in the area to provide sufficient amounts of sludge or septage for continuous operation. In many locations, such a concept is highly beneficial, as it addresses the existing problem of septage treatment from on-site systems in the area – a very common deficiency

11.3.3 Small-scale application – drying and composting

The sludge from most DEWATS units is a thick liquid of approximately 3 to 5% solid content. However, the loss of a large amount of water cannot be avoided as large amounts of water are withdrawn with it, the solid content of removed sludge is closer to 2%. These large liquid volumes are difficult and expensive to transport.

For small DEWATS, therefore, stabilised sludge can be spread directly on flower-beds as fertiliser. A thin layer of sludge dries almost immediately and the slight foul smell once a year will be acceptable in most locations.

Where larger amounts of sludge cannot be transported to a more suitable drying place, drying sand-beds can be installed directly next to the treatment facility. By locating the bed approximately 40 cm below the water level of the plant, hydraulic pressure can be used to distribute the sludge in a 20 cm thick-layer. The bed is made up of coarse aggregate (>50 mm diameter) and covered with 10 to 15 cm of coarse sand.

Picture 11_34: Sludge-drying bed and well-stabilised, small sludge cluster. Credit: A. Schmidt

The process comprises steps:

- dewatering – filtration of water through a sand-bed. Process efficiency is a function of the filter area and depth, filter material, sludge loading and sludge properties. Total Solids (TS) can be raised from 1-5% to 15-25%
- drying wind and sun assist in natural evaporation of moisture. Process efficiency is a function of sun and wind intensity, humidity, air temperature, precipitation, sludge properties and loading depth. TS can be raised to 80%

The bottom of the drying bed should be sealed, to prevent groundwater contamination, and a slight slope should lead to drainage pipes for dewatering. In hot and dry climates, a bed can be loaded perhaps five times per year. In the case of moderate temperatures, frequent rain or high humidity, special considerations – like roofs, enclosing structures or longer drying times – are required. Banana plants can be planted in the sludge bed to make the most of moisture and nutrients.

Composting is a natural, aerobic-decomposition process, in which useful microorganisms break down organic matter and produce carbon dioxide, water, humus and heat. Properly heaped compost reaches a temperature of up to 70°C over several weeks of maturation, thereby killing pathogens, including helminths and ova. It requires no special mechanical equipment and produces a final product, humus, which has a value as fertiliser and soil conditioner.

Parameter	Description/Comment
50% moisture content	A handful of squeezed compost should feel moist and retain its form without water dripping from it. If it is too wet, dry organic material must be added. If it is too dry, it must be watered. Protection against rain or solar radiation might be advisable.
Density of 0.6 to 0.8 (promoting aeration)	Use of stiff bulking agents or bedding promotes natural aeration. Compost pile should be turned at least once to move outside material to the inside, ensuring heat treatment of all material.
C:N ratio of 30:1	Different bulking agents can be used to adjust the ratio.
pH value of 5 to 9	Verified with litmus paper; low pH can be raised with lime or other amorphous alkaline substances.

Table 40:
A successful composting process requires:

The largest problem with economic sludge composting is the high water content of sludge. Where large amounts of dry organic matter are available, it can be mixed with dewatered sludge (of at least 25% Total Solids) to achieve the desired Total Solids (TS) and consistency.

A successful composting process requires:

Composting can be practised within permeable boxes or elongated piles called windrows.

- If boxes are used, they must have a door for loading and removal. The walls of the box must either contain openings for oxygen supply from all sides of the compost – or the compost must be turned frequently
- If windrows are used, they should not be more than 1.2 to 1.5 m high with approximately double the width and a natural slope

Since composting demands a solid understanding of the process, some experts argue that it should only be applied for greater amounts of sludge and if a composting facility already exists. Where local knowledge of the process there is with farmers or within solid waste management schemes, sludge composting can be a successful approach.

Picture 11_35 to 11_37: Box composting (left), windrow composting (middle), compost (right)

Humus, the stabilised and sanitised product of composting, is an excellent soil improver, rich in nutrients and with good moisture-retention qualities. The desludging and composting process can be planned in accordance with agricultural cycles to provide the maximum benefit to farmers.

However, premature desludging should be discouraged, as longer desludging intervals produce a safer sludge. Agreements between sludge-treatment plant operators, local farmers or organic-fertiliser producers should be encouraged. Marketing of the final product demands control mechanisms to ensure a high-quality product and might require awareness-raising activities and advertisement campaigns to promote its benefits. Alternatively, sludge compost can be used to cover landfills, or as a raw material for making items such as flower-pots, drainage trays or bricks.

If composting is not possible but sludge is to be used fresh on agricultural land, then the sludge must be put into trenches which are covered by 25 cm of soil, at least. It's not suitable in areas of high ground water.

11.3.4 Large-scale application – sludge and septage-treatment facility

Some DEWATS, particularly those treating animal husbandry or organic industrial wastewater, produce greater amounts of sludge. If there is no sludge-treatment facility nearby, the construction of one should be considered. In most cases, such a facility will offer great benefits to the greater local community – if it is designed to also treat septage from local on-site septic tanks and pit latrines. The following example introduces such a treatment facility.

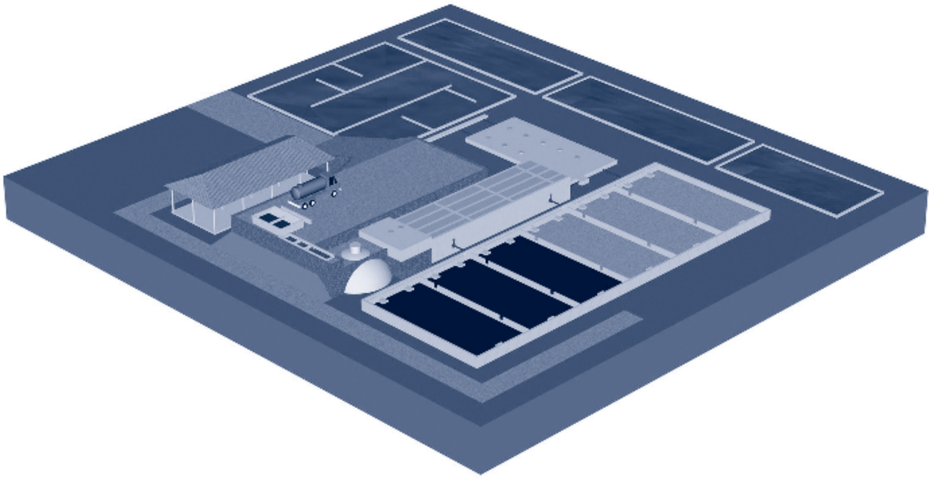
IPLT in Mojokerto, East Java, Indonesia

Mojokerto is a town in East Java with a population of approximately 150,000. As 60 to 80% of its wastewater is treated in on-site sanitation plants (septic tanks, latrines, and grease traps) there is great septage accumulation. The emptying of the septic tanks used to be carried out by a private company, which used three to four trucks to transport and dispose of the untreated septage into a river.

In March 2005, the Municipality of Mojokerto partnered with BEST Surabaya and BORDA to initiate a septage-management and recycling project. BORDA and BEST planned the septage-disposal service and treatment facility (IPLT). The municipality is responsible for construction, while operation will be carried out by BEST in the first year and then handed over to the municipality.

Picture 11_38 and 11_39: Septage-disposal truck, polluted river– misused as a dumpsite

To ensure that the collected septage actually ends up in the treatment plant, the municipality will be using an innovative financing model. The municipality sells 'chips' to the community. When a septic tank is emptied, a chip is passed to the driver of the collection truck, who takes it to the treatment facility. The treatment plant is later paid according to the amount of chips it returns to the municipality.



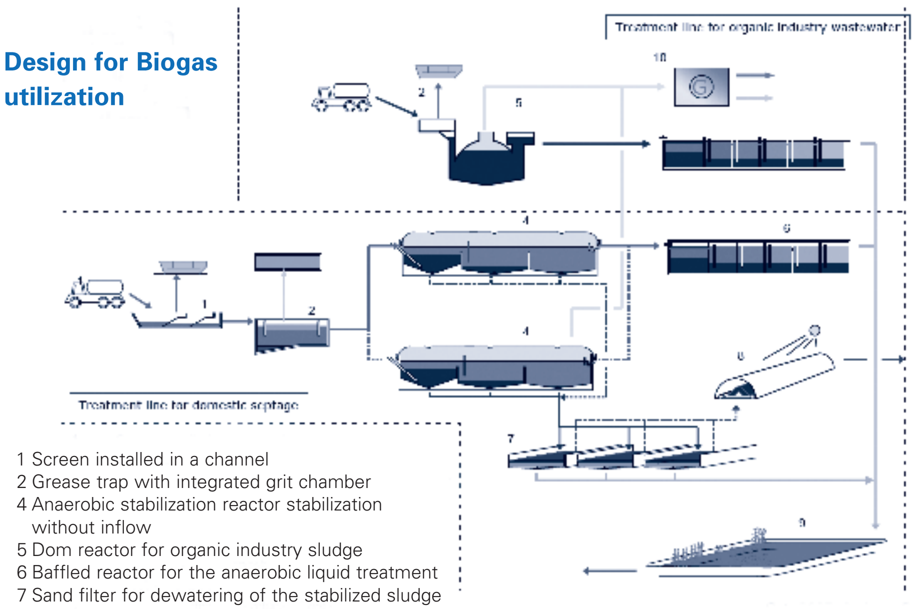
Picture 11_40 to 11_42: IPLT under construction

The facility is designed to handle 32 m³ of septage per day. Its modules are similar to those of DEWATS and its closed components prevent odour pollution. Pre-treatment ensures that the plant is low maintenances. It includes:

- 20 and 10 mm screens to avoid blockage
- a grease trap to prevent fatty accumulating sludge in pipes and reactors
- grit chambers to avoid sand accumulating in channels, pipes and reactors

A stabilisation reactor combines liquid/solid separation with anaerobic treatment. It reduces odour, oTS, COD and BOD, while improving dewaterability and drying. Biogas is produced, collected, and used/burned. The reactor consists of three chambers:

- chamber 1: mixed reactor with siphon feed to mix the sludge and promote biological activity; theoretical hydraulic retention time 1-3 days
- chamber 2: up-flow sludge bed
- chamber 3: sludge sedimentation



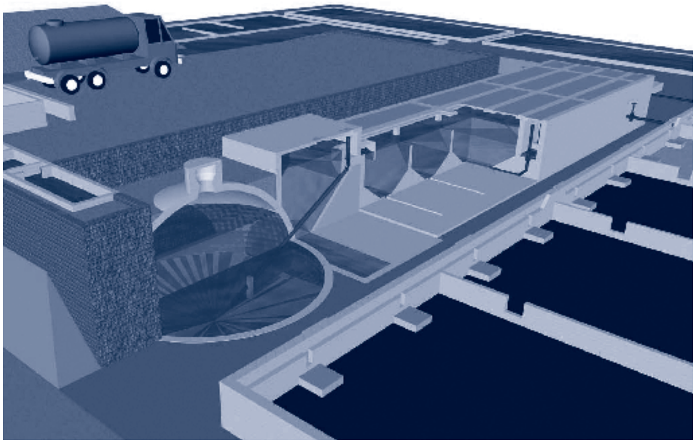
1 Screen installed in a channel
2 Grease trap with integrated grit chamber
4 Anaerobic stabilization reactor stabilization without inflow
5 Dom reactor for organic industry sludge
6 Baffled reactor for the anaerobic liquid treatment
7 Sand filter for dewatering of the stabilized sludge
8 Tunnel dryer for composting and disinfection
9 Aerobic maturation for the liquid phase
10 Biogas utilization for producing heat or electricity

Picture 11_43: Treatment scheme of IPLT, Mojokerto

The installation of two reactors enables alternate operation with a defined retention time for the charged sludge. The suggested sludge retention time is 15 to 20 days. A stripping column oxidises NH_4 and removes NH_3 to prevent inhibition of the anaerobic liquid treatment.

Six sand-filter beds dewater and dry the stabilised sludge. Dewatering performance ranges from 40 to 55% TS during the rainy season and from 50 to 70% TS during the dry season. Separated sludge water is drained. The sludge is composted in tunnel dryers – the consist of a simple floor with a removable greenhouse roof for storm protection. The windrows are aerated with timber air channels "the sludge is" composted for 30 to 50 days. The sludge water or the liquid fraction of the sludge is treated in a baffled filter and constructed wetland.

Picture 11_44 and 11_45: Timber aeration channels; leachate treatment in a constructed wetland (horizontal gravel filter)



Picture 11_46: The technical concept of IPLT Mojokerto

11.4. Reuse of wastewater and sludge

11.4.1 Risks

Wastewater is never hygienically safe. Proper handling of wastewater and sludge is the only successful preventive health method. The farmer who uses waste-water for irrigation must consider the risk to his own health and to the health of those who consume the crops grown by him. He must therefore check whether the wastewater he uses for irrigation is suitable to the crops or pasture ground he intends to water.

Fresh, untreated domestic and agricultural wastewater contains over one million bacteria per millilitre, thousands of which are pathogens - both bacteria and virus. Eggs of worms are found in the range of 1000 per litre. Epidemical statistics re-veal that helminthic (intestinal worm's) infection presents the most common risk from irrigation with untreated wastewater. The risk of bacterial infection comes followed by the risk of virus infection, which is the lowest. Although the removal rates in anaerobic systems are usually over 95%, many pathogens remain even after treatment. The effluent from oxidation ponds is less pathogenic.

Table 41: Survival of pathogens

pathogenes	in sludge and water		in soil	on plant
	10-15° C < days	< days	20-30° C[1] < days	< days
virus	100	20	20	15
bacteria				
salmonella	100	30	20	15
cholera	30	5	10	2
fecal coli	150	50	20	15
protozoe				
amoebae cyst	30	15	10	2
worms				
ascari ova	700	360	180	30
tape worm ova	360	180	180	30

[1] not exposed to direct sun light

The World Health Organisation (WHO) recommends that treated wastewater for unrestricted irrigation should contain less than 10.000 fecal coliforms per litre (1000/100 ml), and less than 1 helminth egg per litre. This limit should be observed strictly since the risk of transmitting parasites is relatively high.

Pathogenic bacteria and viruses are not greatly effected in anaerobic filters or septic tanks because they remain in the treatment plant for only a few hours before they are expelled together with the liquid that exits the plant. Post treatment in a shallow pond that ensures exposure to the sun reduces the number of bacteria considerably.

Those farmers who use sewage water for farming or sludge as a fertiliser are exposed to certain permanent health risks. These health risks are controlled within organised and specialised wastewater farming or within commercial horticulture, because of certain protective measures that are taken, such as the use of boots and gloves by the workers and the transportation of the wastewater in piped systems. However, such precautions are very unlikely in small-scale farming. Plants are either watered individually with the help of buckets or trench irrigation is used. The flow of water is usually controlled by small dykes which are put together by bare hand or bare foot making direct contact with pathogens unavoidable.

A shallow storage pond to keep water standing for a day or more before it is used may minimise the number of pathogens, but would hardly reduce the indirect health risk. It is also likely that children will play here, ducks will come to swim and animals may start to drink. Fencing may help. A more foolproof preventive measure may be an establish health-education programme that reminds users of the dangers – and the precaution they need to take.

Consumers of crops grown by such means and animals that graze on pastures that are irrigated with wastewater are also endangered. Since bacteria and virus are killed by a few hours, or at most a few days of exposure to air, wastewater should not be spread on plants which are eaten raw (e.g. lettuce) for at least two weeks prior to harvesting. India has prohibited the use of wastewater irrigation for crops that are likely to be consumed uncooked.

Since bacteria and virus stay alive much longer when wastewater percolates into the ground, root crops like potatoes or carrots except for seeds or seedlings should not be irrigated with wastewater.

Table 42: WHO guidelines for wastewater use in agriculture. Source: WHO 1989

category	reuse conditions	treatment required
A	irrigation of crops to be eaten uncooked, sports fields, public parks	series of stabilisation ponds
B	irrigation of cereal- industrial- and fodder crops,pasture and trees	10 days retention in stabilisation ponds
C	localised irrigation of crops of category B, no contact by workers or public	at least primary sedimentation

11.4.2.Groundwater recharge

Recharge of groundwater is probably the best way to reuse wastewater particularly since the groundwater table tends to lower almost everywhere. Wastewater had been freshwater, and freshwater drawn from wells has been groundwater before. Sustainable development is directly related to the availability of water from the ground. Thus, recharging of this source becomes absolutely vital to human civilisation. The main question is how far the wastewater needs treatment before it may be discharged to the ground.

11.4.3 Fishponds

Wastewater is full of nutrients which, when directly used by algae, water plants and lower animals could become fish feed. But fish need also oxygen to breathe, which must be dissolved in water in the pure form of O_2 (4 mg/l for carp species, > 6 mg/l for trout species). Because free oxygen is needed for degradation of the organic matter present in wastewater, it cannot be expected to be in sufficient supply for the survival of fish. Therefore, pre-treated wastewater must be mixed with freshwater from rivers or lakes, otherwise wastewater ponds must become so large that oxygen supply via pond surface overrules the oxygen demand of the organic load.

The organic load on fishponds should be below 5g BOD/$m^2 \times d$ before 5 times dilution with freshwater. This implies that if the chances of dilution are non-existent, the organic load may be 1 g BOD/$m^2 \times d$.

If possible, there should be several inlet points in order to distribute organic matter more equally where it comes into contact with oxygen quickly. As mentioned before a turbulent surface increases the oxygen intake, and cooler temperatures increase waters ability to store free oxygen. However, it is not worth-while trying to increase oxygen intake by specialy shaped inlet structures or similar measures. At a stage where oxygen deficiency can only be little, oxygen absorption is also little.

The pH should be 7 to 8. Fish culture is not possible if wastewater may be toxic or polluted by mineral oils, temporarily or permanently.

Wastewater should not be mixed with freshwater before the fishpond. Otherwise wastewater nutrients would initiate the heavy growth of fungi, algae and other species without being consumed by fish. When a fishpond is started, it first should be filled with fresh water, wastewater is added later.

When using natural lakes for wastewater-based fishery it should be known, whether the lake is legally considered to be part of the treatment system or already part of the environment in which wastewater is discharged. With other words, it must be clear whether discharge standards must be observed at the inlet or whether the effluent of the lake will do.

The kind and condition of fish are an indicator of water quality. Carp type can live in water with a lower oxygen content and are the most common species in wastewater-based fish culture. Tilapia has become the most common "Development Project Fish" and is also growing well in wastewater ponds. Tench species often have difficulty surviving, because they take feed from the ground and run into get problems with anaerobic bottom sludge. It is advisable to empty the ponds once a year to remove sludge or at least expose the bottom sludge to oxygen for stabilisation.

Fishponds are normally more turbid than other ponds, because fish swirl up sludge from the ground. Trout species survive surprisingly well, despite higher turbidity, when the oxygen content is sufficient. However, it should be clear that more specired knowledge of fish species, fish production and marketing is needed than can be contained in this chapter. More information is available from the regional offices of fishery departments and should be obtained before starting a wastewater fish-farming system.

Fishponds have a hydraulic retention time of 3 to 10 days and a depth of 0.5 to 0.8 m. Net fish production is in the range of 500 kg/ha (50 g /m²), 900 to 1200 kg/ha are said to be harvested from Calcutta's municipality fish farm. There is also the possibility of raising fish in 2.5 to 3 m deep ponds where different kinds of fish live in different strata. An almost unbelievable 12,000 kg/ha are claimed to have been harvested in Brazil in such ponds every year. A higher fish population produces more sludge which reduces the amount of free oxygen. Whether wastewater-based fishery becomes a viable business depends on the market price of fish and operating costs fishery. Fingerlings must be kept separate because fish, when set free, should weight 350 g in order to be too heavy for fishing birds. Losses can reach 50% when fishponds become an ecological niche which attracts fish-hunting birds.

Fish lose the foul taste of wastewater if they are kept for a few days in fresh water before consumption. This also reduces the risk of pathogen transfer. Fishermen need to be aware that the wastewater which always bears a certain, albeit small, health risk.

11.4.4 Irrigation

Treated domestic or mixed community wastewater is ideal for irrigating parks and flower gardens. Irrigation normally takes place in the evening or early morning so that people wait be bothered, even not by the slightly foul smell of anaerobic effluent. Nonetheless, the irrigation of public parks is often forbidden by law.

For an irrigation rate of 2 m per year (20,000 m^3/ha) – the normal requirement in semi-arid areas – even welltreated wastewater with concentrations as low 15 mg/l of total nitrogen and 3 mg/l total phosphorus provides 300 kg N and 60 kg P per ha via irrigation without additional cost; at the same time the respective amount of groundwater is saved.

In areas where there is plenty of rain less water is needed for irrigation. So presettled but otherwise fresh wastewater may be more appropriate with respect to fertiliser. With 0.1 m per year (1,000 m^3/ha) of fresh wastewater for irrigation, some 60 kg nitrogen, 15 kg phosphorus and a similar amount of potassium could be applied per ha. However, domestic wastewater in modern households sometimes lacks the potassium which might need to be added to mobilise nitrogen and phosphorus.

As this book deals with wastewater, it does not provide detailed information on either general or specific local questions of agriculture or the nutrient requirements of different crops. Each farmer has to find out his or her own preferred method and his or her own way of using efficient and safe quantities of water. The practical farmer knows which nutrients are needed for which crop and a trained agriculturist would also know – from wastewater analysis – whether the composition of nutrients and trace elements suits the proposed plantating. He or she will also know, from that analysis, whether too many of toxic elements remain in the water (toxic elements might being if the COD is much higher than the BOD). Such tests are advisable when using industrial or hospital wastewater for the first time.

The person responsible for of the wastewater source is obliged to inform farmers about toxic or otherwise dangerous substances in the effluent, for example, radioactive elements from x-ray laboratories.

Original saline water will remain saline even after intensive treatment. Copper and other metals, especially heavy metals, accumulate in the soil. Long-term application of such water will spoil the soil forever.

11.4.5 Reuse for process and domestic purposes

Pathogenic wastewater – from domestic sources, slaughterhouses or animal stables should not be reused for any purpose, except irrigation. Partly treated organic wastewater (this is more or less all wastewater from DEWATS treatment) should not be reused as process water in industries or as flushing water in toilets. Reusing wastewater will always means that some traces of organic matter or toxic substances remain or accumulate. Reuse also means longer retention times in a closed system which might facilitate anaerobic processes within pipes and tanks which will cause corrosion. There is also a theoretical risk of biogas explosion.

To suppress organic decay one may have to add lime, which might form limestone inside the system or other inhibiting substances which would make appropriate final wastewater treatment costly. For example, even the first washing water in a fruit processing plant or a potato-chip plant might already contain too much organic matter for any reuse without lime being added to suppress fermentation.

The chance of re-circulating parts of the water to serve the production process is limited, especially when the wastewater engineer and the production engineer don't have the necessary knowledge. The pollution content and level treatment needed, as well as demand of water required for consumption – and the wastewater flow over a given period of one day (or one season) – must be investigated. It might be necessary to build intermediate water stores and install additional pumps. Wastewater reuse is an option that which sounds very reasonable in the context of sustainable development. But, the problems means it can't be to recommended.

Reusing industrial wastewater which is only slightly polluted and perhaps not organically polluted, is a completely different matter. For example, press water in a soap factory may be reused for mixing the next load of soap paste. All water consuming modern industries have reduced their water consumption considerably in the last few years. In most countries, India and China, water-consumption limits are obligatory for many industrial processes including sugar refining, brewering, canning, etc.; Saving water in the process is always better than reusing water which has been carelessly wasted and polluted.

11.5 Biogas utilisation

11.5.1 Biogas

All anaerobic systems produce biogas. 55 to 75% of methane (CH_4), 25 to 45% of carbohydrate (CO_2) plus traces of H_2S, H, NH_3 go to form biogas. The mild but typical foul smell of biogas is due to the hydro-sulphur, and after which transforming into H_2SO_3, is also responsible for the corrosive nature of biogas. The composition rate of biogas depends on the properties of wastewater and on the design of the reactor – the retention time. Theoretically, the rate of methane production is 350 l per kg removed BODtotal. In practice however, methane production should be compared to 1 kg removed COD of which values are closer to the removed BOD_{total} than to the removed BOD_5. By doing so, one assumes that during anaerobic digestion only biodegradable COD is removed, which is involved in the production of methane. In reality, the gas production rates are lower than this because a part of the biogas dissolves in water and cannot be collected in gaseous form. It is also the norm to relate biogas production to organic dry matter in case of very strong viscous substrate, 300 to 450 l biogas per kg DM can be expected.

The calorific value of methane is 35.8 MJ/m³ (9.94 kwh/m³). The calorific value of biogas depends on the methane content. Hydrogen has practically no role. As a rule of thumb, 1 m³ biogas can substitute 5 kg of firewood or 0.6 l of diesel fuel.

industry	COD per product kg/to	COD removal %	relative gas production m³ CH_4/COD_{in}	methane content %
beet sugar	6-8	70-90	0.24-0.32	65-85
starch – potato	30-40	75-85	0.26-0.30	75-85
starch – wheat	100-120	80-95	0.28-0.33	55-65
starch – maize	8-17	80-90	0.28-0.32	65-75
molasses	180-250	60-75	0.21-0.26	60-70
distillery – potato	50-70	55-65	0.19-0.23	65-70
distillery – corn	180-200	55-65	0.19-0.23	65-70
pectine		75-80	0.26-0.28	50-60
potato processing	15-25	70-90	0.24-0.32	70-80
sour pickles	15-20	80-90	0.28-0.28	70-75
juice	2-6	70-85	0.24-0.30	70-80
milk processing	1-6	70-80	0.24-0.28	65-75
breweries	5-10	70-85	0.24-0.33	75-85
animal slaughter	5-10	75-90	0.26-0.32	80-85
cellulose	110-125	75-90	0.26-0.33	70-75
paper/board	4-30	60-80	0.21-0.28	70-80

Table 43: Potential biogas production from some selected industrial processes. Source: ATV, BDE, VKS

11.5.2 Scope of use

Biogas may be used in ovens for cooking or in combustion engines to generate power. If is use will depend on whether enough can be supplied regularly to meet the minimum requirement of a particular use. If biogas cannot be utilised, it should be released in the air rich safe ventilation. It is pointless to collect, store and distribute biogas when there is no real need.

It is not essential extract carbohydrate (CO_2) before biogas is used. But it might be advisable to remove an unusually high H_2S content with the help of iron oxide: Biogas flows through a drum or pipe filled with iron oxide (e.g. rusted iron borings). The oxygen reacts with the hydrogen to form water, while sulphur and iron (or sulphide of iron) remain. The iron may be reused if it becomes rusty again from exposure to air.

The minimum amount of biogas for a household kitchen requires is approximately 2 m³/d. Approximately 20 to 30 m³ of domestic wastewater is required daily to produce the minimum amount of gas. From an economic point of view, biogas utilisation from wastewater becomes meaningful if the strength of the wastewater is at least 1000 mg/l COD and the regular daily flow is 20 m³.

The best use of biogas is for heat production. Biogas burners are simple in principle and can be made from converted LPG-burners. Biogas can be used for cooking in the home and canteens, or for drying and heating as part of industrial processes. The very best use of biogas would be as fuel for the same process that produces the wastewater.

Biogas can also be used in gas lamps. But the light from a biogas lamp cannot compete with an electric light.

Biogas can be used as fuel in diesel engines and Otto motors. As the ignition point of biogas is rather high, it will not explode under the pressure of a normal diesel engine. So, around 20% of diesel must be used for ignition, together with biogas. Also, the slow flame speed of biogas is better suited to the slowly revolving diesel engine than Otto motors. Biogas would not have enough time to burn completely with engines that run with more than 2000 revolutions per minute.

11.5.3. Gas collection and storage

Biogas is produced within wastewater and sludge, from which it rises in bubbles to the surface. The gas must be collected above the surface and stored until it is ready for use. Even when gas production is regular, the accumulation of useable gas is irregular. Gas bubbles cause turbulence which leads to the explosive release of gas in a chain reaction. Stirring substrate, especially stirring sludge, has a similar effect. As a result of this, gas production fluctuates by plus/minus 25% from one day to the next. The volume of gas storage must provide for this fluctuation.

The volume of gas in stock changes according to gas production and the pattern of gas consumption. With rigid structures, the volume of the storage tank either changes as the volume of gas present changes, or the gas pressure increases along with the stored volume. In fixed- dome plants, and with flexible material such as plastic foils, both the volume and the pressure fluctuate.

There are two main systems for rigid materials, namely:
- the floating drum and
- the fixed dome

For flexible material there are two variants, as well:
- the balloon, and
- the tent above water

The floating drum is a tank that floats on water, the bottom of which is open. The actual storage volume changes depending on the amount of gas available and the drum rises above the water according to gas volume. The drum is normally made out of steel. To avoid corrosion, materials such as ferro-cement, HDP and fibreglass have also been tried. As a rule, only very experienced workshops have been successful with these materials. Most find leakage a problem. The gas pressure is created by the weight of the drum (the weight is divided by the occupied surface area to calculate the pressure). A safety valve is not required as surplus gas is released under the rim when the drum rises beyond a certain point.

The fixed dome principle has been developed for biogas digesters for rural households as an alternative to the floating drum with its corrosion. The fixed-dome plant follows the principle of displacing liquid substrate through gas pressure. The gas pressure is created by the difference in liquid level between the inside and outside of the closed vessel. If there is very high gas pressure, the outlet pipe functions as a safety valve. The inner level, therefore, of the outlet pipe must be lower than that of the inlet.

Picture 11_47: Floating drum plant. The drums are being lifted for re-painting which allows a view of the double-ring wall of the water jacket. Constructed by LPTP and BORDA for a slaughter-house in Java/ Indonesia. [Credit: Sasse]

In biogas plants that here are relatively high gas production compared to the volume of substrate, an expansion chamber is needed to sustain gas pressure during use. In the case of wastewater, where the volume of water is relatively large compared to the volume of gas production, an expansion chamber may not be required because the in-flowing wastewater replaces the wastewater, which has been pushed out by the gas. For this reason gas consumption must correspond with intensive wastewater inflow. An expansion chamber is required when there is little to no wastewater flow during gas consumption. It is not when the simultaneous volume of consumed gas is less than the volume of wastewater inflow.

The surface area of an anaerobic treatment tank is relatively large compared to the amount of biogas produced. Consequently, fluctuation in liquid levels as a result of variation in gas volumes in the upper part of the reactor are relatively small. All the same, it may influence the design, especially the level of baffles needed to retain floating solids.

Biogas is an end-product of decomposition and, therefore, has very fine molecules that can pass through the smallest crack and the finest hole. So its storage must be as gas-tight as a bicycle tube. The usual-quality concrete and masonry is not sufficiently gas-tight – bricks are porous and concrete has cracks. So, bricks and concrete must be well plastered by applying several layers and adding special compounds to the mortar to minimise shrinking rates. Several layers of plaster help to cover the cracks on one layer with the next layer of plastering, the hope that the cracks in different layers do not appear at the same spot.

Table 44: Prescription for gas-tight plaster. The method was developed by CAMARTEC/GTZ in Arusha, Tanzania and has been successfully applied in many countries since 1989. Source: Camartec, BORDA

1st layer	cement – water brushing
2nd layer	cement plater 1:2.5
3rd layer	cement water brushing
4th layer	cement plaster 1:2.5 with water proof compound
5th layer	cement – water brushing with water proof compound
6th layer	cement plaster 1:2.5 with water proof compound
7th layer	cement – water finish with water proof compound

A structure under pressure cannot develop cracks, therefore the structure of the gas storage should be under pressure whenever possible. This is the reason why anaerobic reactors should have arched ceilings, So that a heavy-soil covering creates the required pressure. Normally, baffled septic tanks and anaerobic filters are rectangular. As it is difficult and expensive to make these structures gas-tight, and considering the fact that gas production is greatest in the first part of the reactor, it may be reasonable to collect gas from the first chambers only. These chambers must be completely gas-tight; rear chambers must be ventilated separately.

Tent systems are mostly used with anaerobic ponds. Balloons may be connected to any anaerobic-tank reactor. Balloons and tent systems require the same material. These materials must be gas-tight, UV-resistant, flexible and strong. PVC is not suitable. The weakest points are the seams and in particular the connections between the foil and the pipes. To secure gas tightness, foils of tent plants are fixed to the solid structure below the liquid level. Foil covering may also be fixed to frames floating on the wastewater. Balloons should be laid on a sand bedding or hung on belts or girdles. It may be necessary to protect them against damage by rodents. The gas pressure must be kept under control to match the permissible stress of the material, especially at joints. Fitting a safety valve, which functions as a water seal on gas pressure, should solve this problem.

Balloon and tent systems, unless securely fenced and protected against stones or rubbish thrown by children, are not suitable for domestic plants.

11.5.4 Distribution of biogas

Normal water-pipe installation technology may also be used for biogas distribution in DEWATS. But ball valves should replace gate valves. All parts should be reasonably resistant against corrosion by sulphuric acid. The joints in galvanised-steel pipes should be sealed with hemp and grease or with special sealing tape. Joints of PVC pipes must be glued; the glue must be spread around the total circumference of the pipe.

Biogas always contains a certain amount of water vapour, which condenses to water when the gas cools down. This water must be drained; otherwise it may block the gas flow. Drain valves or automatic water traps to avoid blockages must be provided at the lowest point of each pipe section. Pipes must be laid in a continuous slope towards the drain points; straight horizontal pipes should not sag.

Gas pressure drops as the pipe gets longer, and more so with smaller pipe diameters. The pipe dimandes must be larger when the point of consumption is far off. Long distances are generally not a problem, but should be kept as short as possible for economic reasons. Connecting stoves or lamps with a piece of flexible hose to the main distribution pipe means that equipment can be moved without disconnecting the pipe. It also allows for condensed water to be drained.

In the case of fixed-dome plants, a U-shaped gas-pressure meter (manometer) could be installed near the point of consumption where it is difficult to see the amount of gas available.

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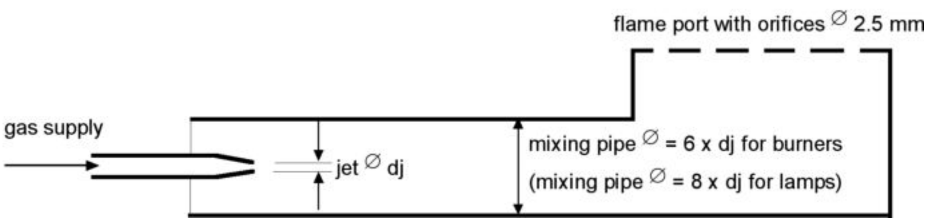
11.5.5. Gas appliances

In principle, biogas can be used in the same way as any other gaseous fuel, for example in refrigerators, incubators, or water heaters. But it's most commonly used in stoves, lamps and diesel engines.

Biogas needs a certain amount of air to burn – on average, one cubic metre of gas requires 5.7 m³ of air for complete combustion, a quarter of what LPG would need. So, LPG burners have smaller jets; consequently the relative air intake compared to biogas burners is greater. The air intake needed for combustion is regulated by the difference of jet diameter to mixing-pipe diameter. For open burners, which draw primary air at the jet and some secondary air at the flame port, the ratio between jet diameter and mixing-pipe diameter may be taken as 1:6. For lamps, where secondary air supply is lower, this figure may be 1:8.



Picture 11_48: Design parameters for gas appliances. The relation between jet diameter and mixing-pipe diameter is important for good performance and efficiency, irrespective of gas pressure. Other parameters are less crucial or can be found by trial and error, for example, one number and diameter of orifices or the length of mixing pipe.

When converting LPG equipment to biogas, the jet must be widened, to around one-sixth of the diameter of the mixing pipe of a burner. These ratios are the same for all gas pressures. There is no need to regulate the air intake when gas pressure changes. However, air requirement is greater when methane content is higher. The difference is too small to be of practical importance. Since the flame speed of biogas is relatively low, biogas flames tend to be blown off when gas pressure is high. It may be advisable to increase the number or size of orifices at the flame port in order to reduce the speed. It is also possible to reduce the flow by placing an obstacle at the flame outlet; for example, a pot set on the burner.

It is trickier to regulate the air-gas mixture in lamps that use textile mantles, because the hottest part of the flame must be directed at the mantle so that the mineral particles glow. If the flame burns inside the mantle, the pressure might be too low and the primary air may be too much. If, on the other hand, the flame burns outside the mantle, there would not be enough primary air and the pressure might be too high. As the composition of biogas also has a role to plan, it is not easy to give general recommendations for lamp design. Practical testing is the only solution.

Diesel engines always have a surplus of air and proper mixing is not required. The gas is connected to the air – supply pipe after the air filter. The mixing of air and gas is improved when gas enters the air pipe by cross flow. Dual fuel engines are started with 100% diesel; biogas is added slowly when the engine is hot and under load. The amount of biogas is regulated by hand. The engine usually starts to splutter when there is too much gas. When the engine runs smoothly, it is regulated like a pure diesel engine with the help of the throttle. For generating 1 kwh electricity, approximately 1.5 m^3 biogas and 0.14 l diesel are required.

12 System malfunction – symptoms, problems, solutions

DEWATS are designed to be particularly robust. Nonetheless, problems may be caused by improper use or operation, insufficient maintenance or structural flaws. A malfunctioning system is a risk to public health and the environment. Reoccurring problems create further complications, if they are not quickly attended to.

As a result, each DEWATS facility requires responsible personnel to:

- recognise the symptoms of a malfunctioning system at an early stage
- identify the cause of the problem
- repair the system, appropriate measures, as soon as possible

There are two main types of system malfunction:

- insufficient treatment of wastewater and
- reduced flow at the outlet of the facility

In case of malfunction, the following sections can be consulted for guidance. They present common symptoms and list possible problems and specific maintenance solutions.

To facilitate troubleshooting, it is beneficial to have a plan of the system and a record of past maintenance activities. Records of pumping, inspection, and other maintenance work should be kept carried out.
It should be clear who is responsible and who can be contacted if the problem reoccurs. A list of specialists (including name, address and phone numbers) should be available – and all staff and users know where it's kept.

12.1 Insufficient treatment of wastewater

Treatment of the wastewater is considered insufficient if it does not correspond to the desired discharge standards in one or several of the following categories:

- BOD
- COD
- Suspended solids
- Smell
- Faecal contamination

Symptoms	
• extensive plant growth (eutrophication) in the discharge water body • fish dying • turbid effluent • frothy discharge • biological and nutrient contamination in nearby wells or surface waters • smell • high pH-value	
Problem	**Solution**
Accumulated sludge within Imhoff tank, septic tank, baffled septic tank, biogas digester or pond system. This leads to a reduction of the hydraulic retention time for treatment.	**determining sludge depth**: 1. wrap one metre of white fabric around the end of a long stick 2. place the stick into the sludge, behind the outlet baffle – leaving it there for one minute 3. remove the stick and note the sludge line 4. If the sludge line is within 30 cm of the outlet baffle or 45 cm within the outlet fitting, the system requires cleaning. For details on correct sludge removal, handling, treatment and reuse – see chapter 11. If many non-biodegradable materials such as plastics, disposable nappies or sanitary towels are found in the sludge – awareness raising for proper use of the system is necessary.

Table 45: Insufficient treatment of wastewater

Problem	Solution
Excessive inflow quantity caused by • increased number of users • changed user habits • structural deficiencies This leads to a reduction of the hydraulic retention time; insufficient time for treatment can lead to high pH levels, caused by volatile fatty acids. It can also lead to backlogging water within the system, or extrusion of water at unforeseen places, if the filter velocity though wetland or filters is insufficient.	Uncontrolled inflow of ground- or stormwater through leaking or damaged pipes or structures must be prevented by locating infiltration points and carrying out repairs. (This can include leaking roofs of community sanitation centre shower or toilet rooms). Uncontrolled stormwater inflow through maintenance openings must be prevented. Attaching wastewater flow from more users than the system was designed for must be discouraged. If the wastewater amount has grown beyond system capacity, a system upgrade is necessary or a parallel treatment system must be installed. Alternatively, awareness-raising activities to promote water-saving habits or fixtures can be applied.
Daily peaks higher than expected	Consider an equalisation tank.

Problem	Solution
Excessive inflow quantity caused by • increased number of users • changed user habits • structural deficiencies This leads to a reduction of the hydraulic retention time; insufficient time for treatment can lead to high pH levels, caused by volatile fatty acids. It can also lead to backlogging water within the system, or extrusion of water at unforeseen places, if the filter velocity though wetland or filters is insufficient.	Uncontrolled inflow of ground- or stormwater through leaking or damaged pipes or structures must be prevented by locating infiltration points and carrying out repairs. (This can include leaking roofs of community sanitation centre shower or toilet rooms). Uncontrolled stormwater inflow through maintenance openings must be prevented. Attaching wastewater flow from more users than the system was designed for must be discouraged. If the wastewater amount has grown beyond system capacity, a system upgrade is necessary or a parallel treatment system must be installed. Alternatively, awareness-raising activities to promote water-saving habits or fixtures can be applied.
Daily peaks higher than expected	Consider an equalisation tank.

Problem	Solution
Excessive inflow contamination caused by: • Inflow of wastewater sources unforeseen in the planning of the facility for example, industrial into domestic wastewater unit). • Excessive BOD and ammonia loadings. Can lead to increased accumulation of settleable solids, high pH-value due to volatile fatty acids or temperature shifts in anaerobic reactors (esp. in the case of illegal industrial connection).	Inflow of inappropriate wastewaters must be prevented. An appropriate facility or an upgrade of the existing treatment plant is required. **Anaerobic ponds:** adding lime (12g/m^3 of the pond) may help to raise the pH value, which may be inhibiting methanogenic organisms and causing smell. **Facultative ponds:** create multiple inlets to the pond. Periodially add of sodium nitrogen as a supplement source of combined oxygen Where possible, public-awareness campaigns can help to minimise pollution through habit change, for example in cooking practices or handling of kitchen waste.
System short circuit caused by • defective separation walls and baffles in tanks or reactors • excessive aquatic vegetation in facultative ponds, reducing the area of flow across the system This leads to less retained settleable solids and reduction of the hydraulic retention time (also see "incorrect retention time" below).	In most cases, draining the facility is necessary to carry out the required repairs or maintenance.

Problem	Solution
Incorrect retention time within the unit can create **smell or effluent-quality problems** In grit chambers, a rotten-egg smell indicates sedimentation of organic matter, due to slow flow velocity/too-long retention time. The removed sand is grey and contains grease. In anaerobic ponds, HRT longer than one day leads to fermentation – not only of the bottom sludge but also the liquid phase. A too-short HRT creates effluent with low pH and emits H_2S odour. In facultative ponds, growth of filamentous algae and moss indicates underloading. Poor flow distribution can be responsible for insufficient retention time and treatment.	Adjustments of flow must be made: • Increasing flow velocity by using fewer parallel units, if available. • Lowering retention time by by-passing overloaded units if the following ones can handle the higher load. Ideally, upgrading of the facility. • Increasing retention time by reducing flow quantity or capping peak-flow (equalisation tank) Check inlets and distribution of flow to treatment units like ponds or wetlands: • Anaerobic ponds: distribution by perforated pipes on the bottom of the pond. • Facultative ponds: create several inlets with uniform distribution to each. • Wetlands: ensure influent distribution across the full width.
Incorrect water level in planted gravel filters, resulting in surface algae growth or insufficient treatment.	The water level should be just below the filter surface; the flow-regulation pipe should be adjusted accordingly, during weekly maintenance tasks.

Problem	Solution
Scum layers or floating material on ponds can hinder some treatment processes.	**Anaerobic ponds:** no measure needs to be taken. The scum layer helps to maintain the absence of oxygen, controls the temperature and prevents the release of bad odours. **Facultative ponds:** remove scum layers, place scum into plastic bags and practise proper garbage disposal. Light and wind penetration of the pond surface should be ensured.
Growth of aquatic or terrestrial vegetation or algae in or on ponds can hinder the treatment process and create smell.	**Anaerobic ponds:** Vegetation on internal or external slopes, as well as in shallow water should be removed completely and regularly. **Facultative ponds:** remove excessive algae growth on the surface, which is prohibiting passage of light, with sieves. Remove excessive aquatic plants restricting the area flow and creating oxygen demand upon plant mortality. **Indicator ponds:** Algae should be removed from the walls by a brush every 14 days.
High concentrations of algae (SS) in the effluent of pond systems	Install baffles to retain and remove algae. Use multiple cells in series with shorter retention time in each.

Problem	Solution
Cloudy weather and low temperature over long stretches of time. reducing treatment efficiency in facultative ponds and causing bad odours.	Reduce the depth of the facultative pond temporarily. If possible, put ponds in parallel operation.
Metal or concrete erosion in anaerobic reactors caused by **insufficient ventilation.**	Check and remove obstructions to the ventilation system, including chamber connections.
Insufficient water seal in the biogas settler causing inefficient treatment and making the system unsafe.	Insert a stick through the hole in the manhole cover to measure the distance until it gets wet. If necessary, refill water seal.

If system malfunction was caused by improper use of the system, awareness raising campaigns should teach users how to prevent such problems in the future.

If system malfunction was caused by insufficient operation and maintenance the existing maintenance schedule should be reviewed and adhered to in the future. A maintenance time schedule and log book is recommended.

12.2 Reduced flow at the outlet of the facility

The effluent volume of a system does not always equal the influent volume – it depends on the amount of evaporation of constructed wetlands or pond systems. However, when the amount of effluent is far less than expected, the system is either clogged at one or more locations and/or is discharging wastewater at unforeseen locations. All control openings should be checked to identify the location causing the irregularity in flow.

Symptoms	
• poorly draining toilets, showers, sinks or drains – nuisance to the users, easily identifiable • extrusion of wastewater at unforeseen places – environmental & health hazard, likely to go unnoticed or to be disregarded. Noticeable as: - pools of water in unexpected places - lush-green vegetation, even during dry weather, in places where there should be none - pathogen or nitrate contamination of nearby wells - dying plants in a planted filter, due to lack of water • reduced flow at the outlet or significant fluctuations – parameter should be monitored by maintenance personnel	
Problem	**Solution**
Pump malfunction, hindering wastewater flow	If a pump is used, check for obstructions and remove them. Check whether the pump-level control is functioning and that the pump is adequately lubricated. Each pump differs slightly, so consult the maintenance manual for the pump for more information about pump maintenance.

Table 46: Reduced flow at the outlet of the facility

Problem	Solution
Clogged pipes – anywhere between the household and location of effluent discharge, including wastewater-treatment plant possible causes include: • improper system use as garbage-disposal for non-biodegradable materials such as plastics, disposable nappies, sanitary napkins, etc. • plant roots growing into the system	Obstructions at manholes should be removed with a shovel and bucket until normal flow is achieved. Pipes should be opened at all maintenance openings to check for backlogged water. The section of clogged pipe lies between the last control opening with backlogged water and its downstream opening. The intermittent section of piping is cleared using boiling water, a drain snake or long pole. Caustic drain openers should not be applied. The reason for pipe obstruction should be identified to prevent identical problems in the future: • roots or saturated soils in the system indicate a damaged pipe.The section of pipe should be replaced. Reasons for pipe damage should be identified. Responsible trees should be removed and/or heavy loading of the pipe with machinery or vehicles should be prevented. • future system misuse should be discouraged through awareness-raising campaigns for users.

12 System malfunction – symptoms, problems, solutions

Problem	Solution
Damaged pipes – anywhere between the household and location of effluent discharge, including wastewater-treatment plant Leaking pipes cause reduced flow in the system and pollute the environment. At times of high groundwater, or during strong rainfall, inflow to the damaged pipe can lead to large fluctuations of flow. Possible causes include: • plant roots growing into the system • unforeseen heavy loading (vehicles or machinery) on laid pipes • leaking joints	Monitoring flow at various control openings helps to locate leaks. Damaged pipes must be replaced. The reasons for pipe damage should be identified to prevent identical problems in the future: • trees responsible should be removed • excessive loading of the pipe with machinery or vehicles should be prevented • during regular maintenance check for leaking system components
Clogged anaerobic filter Inefficient treatment – as discussed in the previous chapter – results in too many suspended solids reaching the filter.	Filter material must be washed with high hydraulic pressure. In most cases the filter material must be removed, cleaned and replaced. Personnel must wear mouth and skin protection. A clogged filter is an indicator that prior treatment is insufficient and too many suspended solids reach the unit. To prevent identical problems in the future, the cause of insufficient treatment can be identified and corrected with the help of the previous chapter/table.

Problem	Solution
Clogged constructed wetland, planted gravel filter Plant growth on only certain parts of the filter can indicate irregular flow – leading to a reduction of retention time until the filter is totally clogged. Possible causes include: • any of the reasons listed in the section "inefficient treatment" – too many suspended solids reach the filter • improper use of the system (great amounts of grease or cooking oils can solidify within the filter and cause clogging) Dead plant matter or extensive weed growth on the filter surface can be responsible for filter clogging.	Inlet and outlet manifolds should be checked for obstructions and cleaned, so that a uniform flow (vital for efficient treatment) can be guaranteed. The plants growing on the filter should be trimmed regularly to not less than 1m. Dead-leaf litter in and around the planted gravel filter should be manually removed every week. The area around the filter should be weeded regularly. If plants grow too densely, they should be thinned out. Look for evidence that heavy equipment has been on the wetland, filter or drainage field, to locate areas of possible compaction and damage. Identification of the cause for clogging may require digging up a small portion of the wetland or drainage field. Maintenance might require draining of the unit, material removal and cleaning. A clogged filter is an indicator that prior treatment is insufficient and too many suspended solids are reaching the unit. To prevent identical problems in the future, the cause of insufficient treatment can be identified and corrected with the help of the previous chapter.

Problem	Solution
Structural deficiencies – cracks and leaks • cracked or improperly sealed walls or floors of treatment units • leaking pipes or pipe joints • loss of water due to flaws in the liner of a constructed wetland – indicated	Testing for leaks or cracks: • Filling the unit with closed outflow; waiting for 24 hours to see if it loses water • Empty the unit with closed inflow; waiting for 24 hours to see if water infiltrates from the outside If so, locate the leaks and repair them.

12.3 Other problems and nuisances

Symptoms • Excessive mosquito breeding	
Problem	**Solution**
Stagnant water turns into a breeding ground for mosquitoes, which cause discomfort for those near the pond, and increase the likelihood of insect-borne diseases such as malaria.	Increase flow, so that water does not become stagnant. Alternatively, introduce lung-breathing fish into the pond (i.e. *Gambusia spp.*).
Clogged biogas lines caused by an accumulation of condensed water.	The valve to release water vapours should be opened daily, after biogas has been switched off for one minute. Biogas burners and pipes should be cleaned every second day to avoid clogging with water vapour and ensure the flow of gas. Ensure that the valve is switched off during maintenance and clean gas holes with a small cloth. Detach the flexible pipe from the biogas pipe and clean the connection.

Table 43: Other problems and nuisances

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