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

BORDA

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A Practical Guide

Editors: Andreas Ulrich, Stefan Reuter
and Bernd Gutterer

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

Ulrich, A., Reuter, S. and Gutterer, B. (eds)
with Sasse, L., Panzerbieter, T. and Reckerzügel, T. (contributors)

WEDC, Loughborough University, UK in association with BORDA, Germany (2009)

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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.
WEDC research and consultancy is directed towards the study of aspects of infrastructure and services (especially related to water and sanitation) in low- and middle-income countries.

BORDA was founded in 1977 in Bremen Germany as a non-profit professional organisation with the goal of developing new methods of using renewable energy to alleviate poverty and, through the implementation of development programmes, to improve the living conditions and social structures in disadvantaged communities abroad.

Unlike other organisations, in the struggle against poverty BORDA focuses on the facilitation of basic needs services in the sectors of water, wastewater, solid waste and energy. To achieve this, partner structures, with the participation of all stakeholders, are advised and assisted in the stablishment and organisation of innovative basic needs services (BNS); this occurs during all phases of planning and construction up to the stages of operation and maintenance.

Editors of the publication are:
- Andreas Ulrich (BORDA Director)
- Stefan Reuter (BORDA Vice Director)
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- Thilo Panzerbieter Sections 11.1–11.3 (Section 11.3 in collaboration with Andreas Schmidt)

Thorsten Reckerzügl has provided substantial documentation.
Editorial contributions: Mary Breen and Michael Smith

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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. In particular the editors would like to express their gratitude to following partner organisations and individuals:

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- India: Consortium for DEWATS Dissemination Society (CDD, Bangalore) and the associated partner network
- China: Sustainable Development Strategy Institute (SDSI) at Zhejiang University of Technology (ZUT), Hangzhou
- BORDA's Regional Programme Co-ordinators Frank Fladerer (BORDA – South-East Asia), Pedro Kraemer (BORDA – South-Asia) and Andreas Schmidt (BORDA – Southern Africa)
- Prof. Chris Buckley (Pollution Research Group, University of KwaZulu-Natal, South Africa) and Ludwig Sasse (retired, pioneer of BORDA's Biogas and DEWATS solutions)

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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 adequate handling.

Recently, decision makers, planners, engineers and civil society stakeholders have launched multiple initiatives to answer the question facing many developing countries: *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 produced 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 ranging from 1–1000m^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 create 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 practice" 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 CBS 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 November 2009

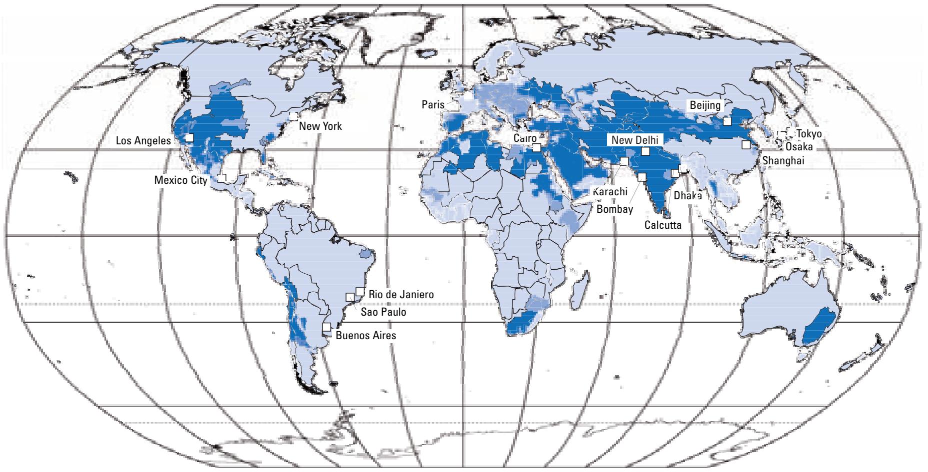
2 Towards comprehensive wastewater and sanitation strategies

2.1 World water resources under threat

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 activities. 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.

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]"



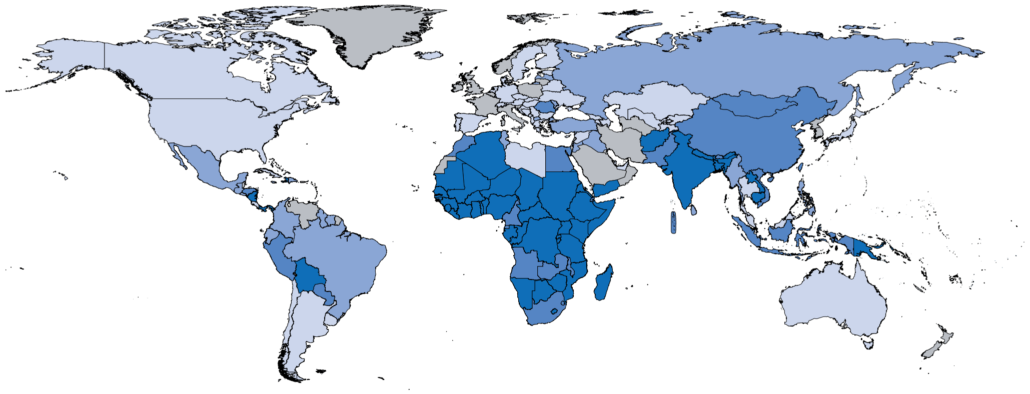
withdrawal-to-availability ratio

■ 0 – 0.2 low water stress
■ 0.2 – 0.4 medium water stress
■ more than 0.4 severe water stress

Picture 2_1: Water stress (2000) in regions around megacities. This map is based on estimated water withdrawals for the year 2000, and water availability during the 'climate normal' period (1961–1990). Results shown in this map were calculated on river basin scale. Source: WaterGAP2.1e by CESR, Kassel, Germany

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, 0.9 billion people still lack access to safe drinking water and 2.5 billion lack access to adequate sanitation. While improvements are monitored on the drinking water side, the challenge on the sanitation side obviously is much bigger than it was thought to be. 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]



Percentage of population using improved sanitation

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

Picture 2_3: Half the developing world are still without improved sanitation; Source: JMP-WHO/UNICEF, 2008

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[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

[2] World Commission on Water 1997

[3] JMP-WHO/ Unicef 2008

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 – 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 other approaches.

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

“Decentralised Wastewater Treatment Systems” (DEWATS) were developed by an international network of organisations and experts. In this handbook, the term DEWATS may be applied in singular or plural form, refering to a single specific system, to the modular systems approach or the whole range of systems, as the case may be. 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:

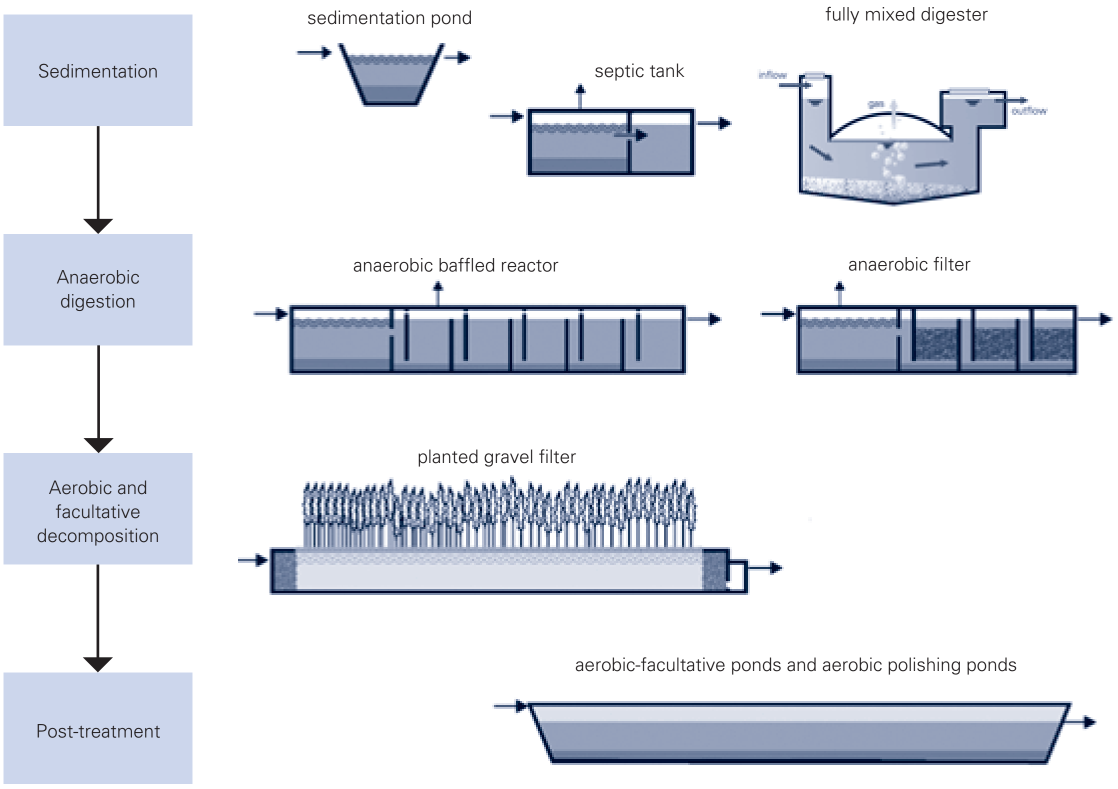
- DEWATS encompass an approach, not just a technical hardware package, i.e. besides technical and engineering aspects, the specific local economic and social situation is taken into consideration
- DEWATS provide treatment for wastewater flows with close COD/BOD ratios from 1m³ to 1000m³ per day and 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 wastewater 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 implemented by the local workforce, high quality standards in planning and construction have 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 consider 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 in a modular manner:

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

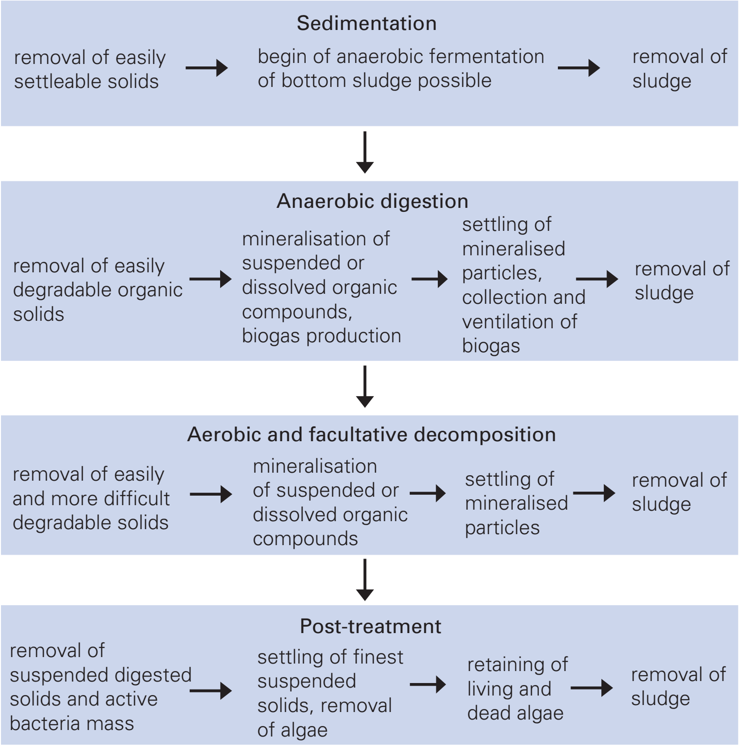


Picture 3_1: DEWATS configuration scheme

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
- 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 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

4 Mainstreaming DEWATS – strategic planning and implementation of sustainable infrastructure

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.

4.1 Strategic planning of sanitation programmes

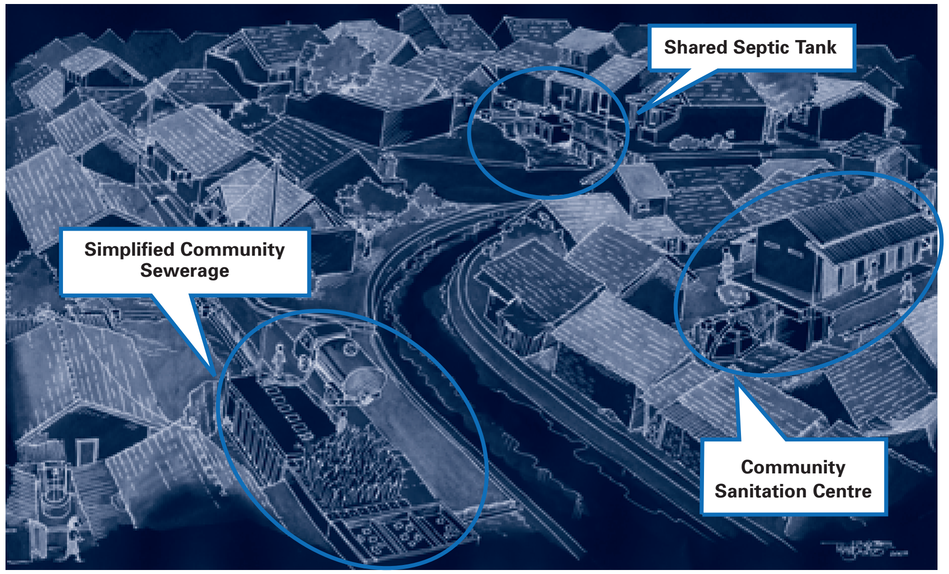
Comprehensive wastewater strategies may consider different options for the treatment and discharge of wastewater:

- 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 treats toilet and bathroom effluent from 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

5 CBS programme planning and implementation

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.

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, maintenance and sludge management

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

CBS programmes respond to the needs of residents in a given area. 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 toilets, 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 programmes should offer different options for improved sanitation facilities – here a pour-flush toilet

6 CBS programme – detailed procedure for implementation

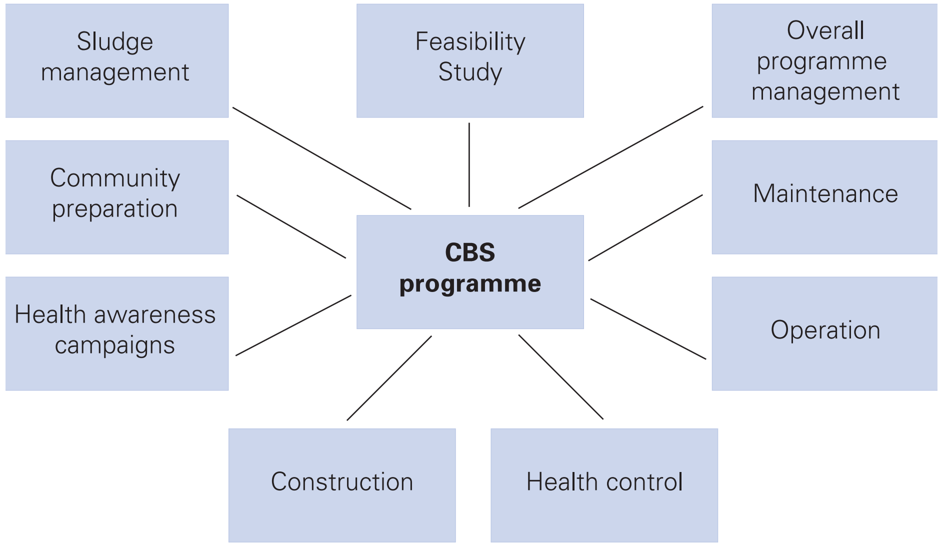
The success of a CBS programme depends significantly on implementing the steps in the right order. The organisation or the group of initiating bodies, taking the lead in launching a project should be aware of the complexity and usefulness of a comprehensive approach. Success depends on the co-ordinated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

6.1 First planning activities

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 in 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

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

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.

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.

Pathogens, including helminth eggs, protozoal cysts, bacteria and viruses, are responsible for innumerable cases of disease and death in the world.

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.

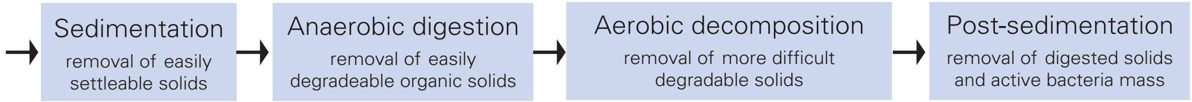
Treatment consists of a wide range of procedures that relieve the negative effect of the pollutants, by removing or changing harmful substances into a harmless or less-harmful state. DEWATS treatment depends on natural bio-chemical and physical processes including:
- degradation of organic matter until the point at which chemical or biological reactions stop (stabilisation)
- physical separation and removal of solids from liquids
- removal or transformation 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 mediated (bio-chemical processes). The processes are the result of the metabolism by micro-organisms, in which complex and high-energy molecules are transformed into simpler, low-energy molecules. Metabolism is the break-down of organic matter (from feed to faeces) to gain energy for life, in this case for the life of micro-organisms, which store and release the gained energy in the form of ATP (adenosine triphosphate). A few chemical reactions happen without the help of micro-organisms. Most of the micro-organisms involved are biologically classified either as bacteria or as archaea. In the past, archae were viewed as an unusual group of bacteria (archaebacteria). Due to their different evolutionary history, they are now classified as a separate domain. That is why "methanobacteria" according current classification are no longer bacteria but archae. In order to avoid confusion, the generic term "micro-organisms" is used.
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").

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

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 micro-organisms, which have differing growth rates and prefer different feeds. Some micro-organisms grow at a slower rate than others. As not all the enzymes required for degradation are initially found in all substrates, the micro-organisms 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 micro-organisms".

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

To protect the "weaker" (slower) micro-organisms, it is advisable to artificially separate microbial 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" micro-organisms find their food after the "fast" ones 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 reactor, the efficiency of the treatment in subsequent chambers justifies its higher cost; processes, which require sequencing batch operation involving technical equipment and process 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 "fast" carbon oxidisers.

In the case of the addition of plant material to an anaerobic digester, precomposting of plant residues before anaerobic digestion is another example of simple phase separation. As lignin cannot be digested anaerobically (it requires peroxidase enzymes usually produced by fungi), it is decomposed aerobically. Afterwards, anaerobic micro-organisms can reach the inner parts of the plant material in the digester.

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, what kind of treatment is necessary and the dimensions of each unit, 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

Textbooks on the analysis of wastewater should be consulted for laboratory techniques or comprehensive handbooks on wastewater, such as Metcalf and Eddy’s *“Wastewater Engineering”*.

8.1.1 Control parameters

Volume

The daily volume or the flow rate of wastewater determines the required size of the building structure – on 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 rate 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 representative sample. In the case of DEWATS, it is often easier and more practical to measure or enquire about the water consumption (per capita consumption of water from taps and/or wells) 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 planted gravel filters will be exposed to rain (and evaporation). 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 planted gravel filter after eroding the surrounding area.

For high-rate reactors, like anaerobic filters, anaerobic baffled reactors and UASB, the flow rate could be a crucial design parameter. If exact flow data are 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 the flow rate fluctuation.

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.

9 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, fully mixed digesters or Imhoff tanks
- secondary anaerobic treatment in baffled reactors (baffled septic tanks) or fixed-bed filters
- 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.

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

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 baffled reactors or baffled septic tanks function as multi-chamber septic tanks. They increase biological degradation by forcing the wastewater through active sludge beneath chamber-separating baffles. All baffled reactors 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.

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 micro-organisms 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 ratio. Upstream Anaerobic Sludge Blanket (UASB) reactors utilise a floating sludge blanket as a biologically active filter medium.

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

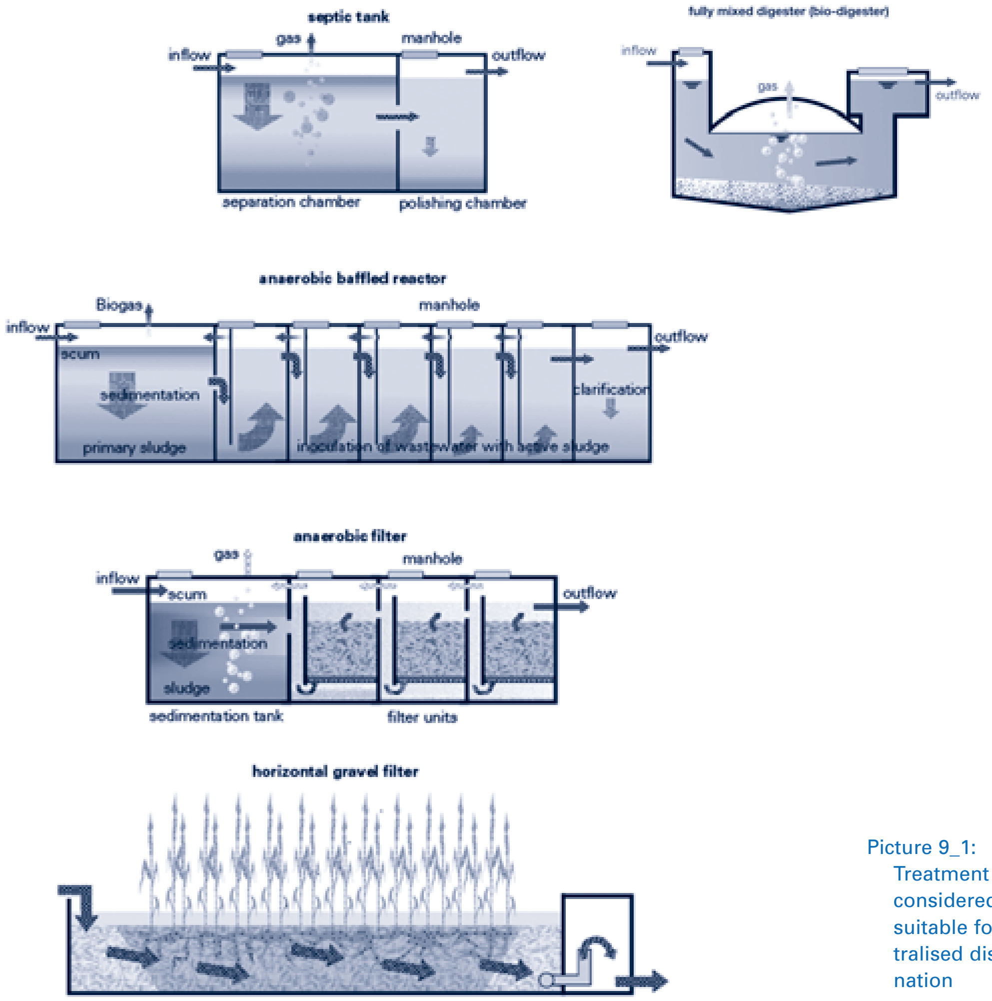
Horizontal gravel filters are sub-surface, flow constructed wetlands, which provide effective, facultative treatment and filtration, while allowing for appealing landscaping. Constructed wetlands are used for wastewater with a low percentage of suspended solids and COD concentrations below 500mg/l.

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 300mg/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

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 input data is correct, 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 in mind that DEWATS provides a set of approaches. The equations used in the technical spreadsheets do rely on certain assumptions. 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. It 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, although "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 4.90m to 5.60m long"; he or she must say: "The length should be 5.35m". 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 350mg/l, when in reality it is only 300mg/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 or having to enlarge 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 an 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 =3^2, square root of 9 could be =SQRT(9) or =9^1/2, cubic root of 27 would be =power(27;1/3) or =27^1/3. 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 well-known 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.

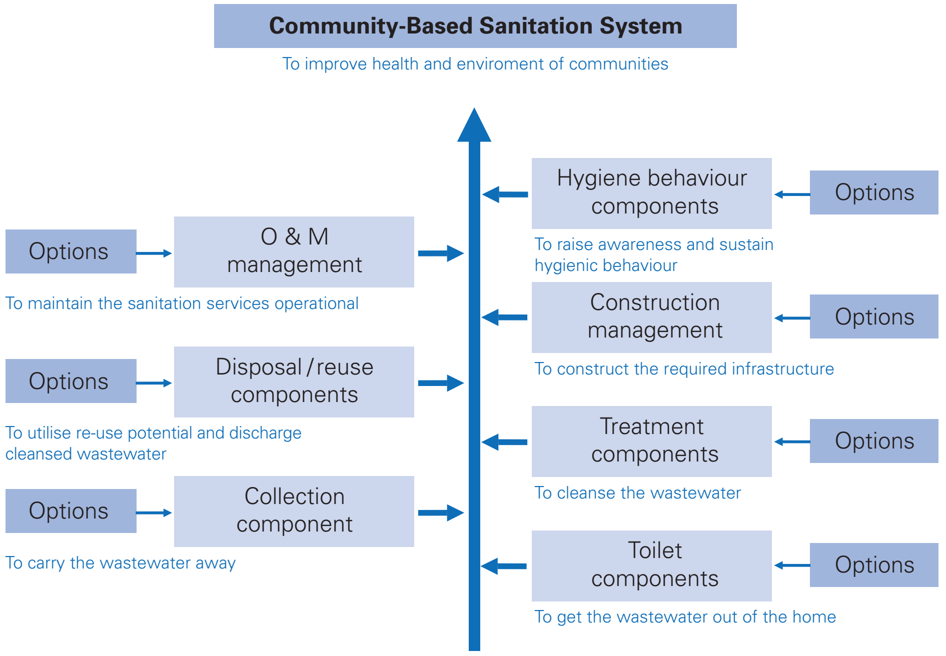
The formulas are simple. Besides basic arithmetical operations, they use only one logical function, namely the "IF"-function. For example:

> 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.

11 Project components: sanitation and wastewater treatment – technical options

The other components of DEWATS and DEWATS/CBS systems along the sanitation chain before and after the wastewater treatment are:

- toilets
- collection systems
- reuse and disposal systems, including sludge treatment and biogas applications
- construction management
- management of operation & maintenance
- health and hygiene behaviour



Picture 11_1
Community-Based Sanitation System: technical options along the sanitation chain

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.
While operational and process related issues are dealt with in chapters 5 and 6, this chapter presents technical options for toilets, collection systems, sludge accumulation and treatment, the reuse of wastewater and sludge as well as biogas utilisation.

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:

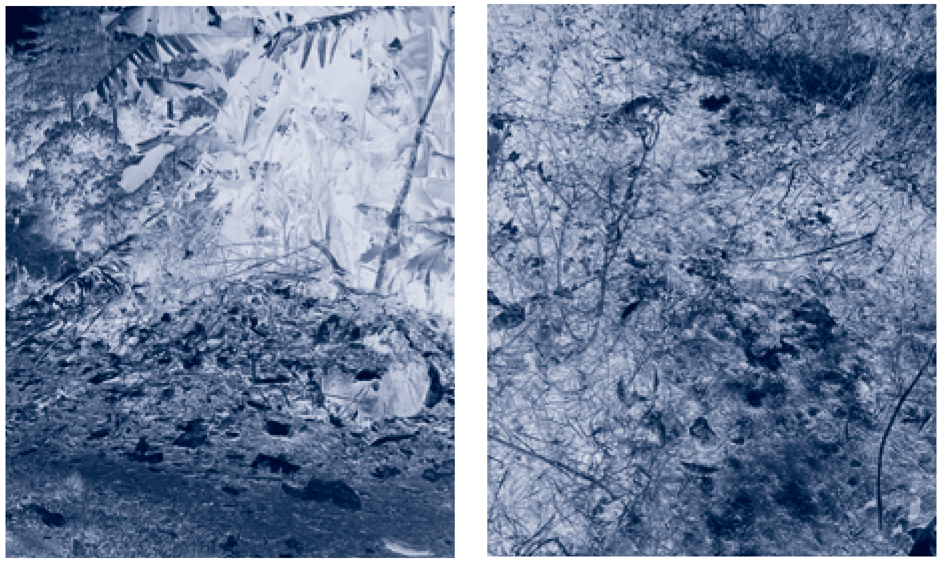
- Privacy – the need for privacy makes it important for a toilet to have a good shelter. Providing a door or enclosed entrance, or constructing it away from busy locations, makes the toilet nicer to use
- Safety – a poorly constructed toilet can be dangerous to use. If it is far from the home, women 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 and to adapt designs to suit local conditions and cultural preferences.

11.1.1 Common practices to be discouraged

Open defecation

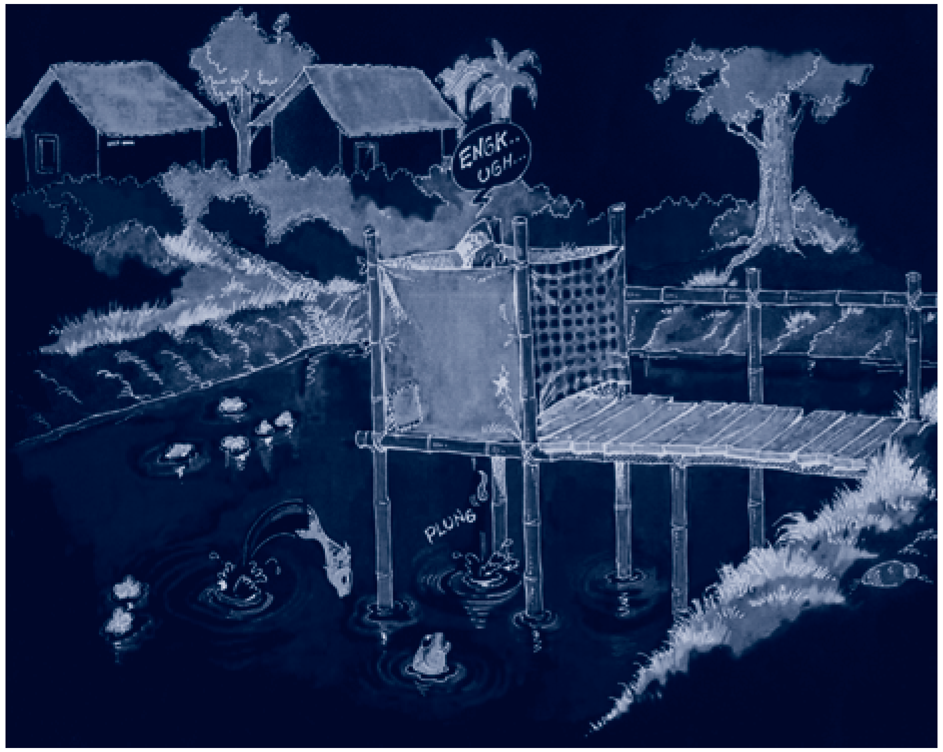
The lacking of sanitation facilities forces large parts of the world's population to defecate openly. Depending on the location, refuge is sought in the forest, jungle, lakes, rivers or the ocean. Apart from lacking privacy and the obvious associated hygienic-health risks, open defecation places humans 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

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 (see operation & maintenance manual referred to in picture 6_25, page 128).
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 is 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, anaerobic baffled reactor, 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 30cm of the outlet baffle or 45cm within the outlet fitting, the system requires cleaning. For details on correct sludge removal, handling, treatment and reuse – see section 11.3. 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 42:
Insufficient treatment of wastewater

13 List of abbreviations

ABR	Anaerobic Baffled Reactor
AF	Anaerobic Filter
BALIFOKUS	BaliFokus Foundation (NGO), Indonesia
BAPPENAS	National Development Planning Agency, Indonesia
BEST	Bina Ekonomi Sosial Terpadu – Institute for Integrated Economic & Social Development (NGO), Indonesia
BMZ	Bundesministerium für wirtschaftliche Zusammenarbeit und Entwicklung – German Federal Ministry for Economic Cooperation and Development
BNS	Basic Needs Services
BOD	Biological Oxygen Demand
BORDA	Bremen Overseas Research and Development Association (NGO), Germany
CBS	Commyity-Based Sanitation
CDD	Consortium for DEWATS Dissemination Society (NGO), India
CERNA	Centre d'Economie Industrielle; the Cerna is the Centre of Industrial Economics at Mines ParisTech
CESR	Center for Environmental System Research, University of Kassel, Germany
COD	Chemical Oxygen Demand
CPCB	Central Pollution Control Board, under the Indian Ministry of Environment and Forests
CSC	Community Sanitation Centre
DALY	Disability Adjusted Life Year
DED	Detailed Engineering Design
DEWATS	Decentralised Wastewater Treatment System(s)
DM	Dry Matter
DO	Dissolved Oxygen
EAWAG	Swiss Federal Institute of Aquatic Science and Technology
EEA	European Environment Agency
EoI	Expression of Interest
GIS	Geographical Information System
GDP	Gross Domestic Product
GP	Gram Panchayat (Indian Government Administration on Village level)
HRT	Hydraulic Retention Time
IDR	Indonesian Rupiah (currency)
INR	Indian Rupees (currency)
IPLT	Indonesian name for municipal sludge treatment plant
JMP-WHO/UNICEF	The Joint Monitoring Programme for Water Supply and Sanitation is co-funded by WHO and UNICEF
LCA	Life Cycle Assessment
LCM	Life Cycle Management
LPTP	Lembaga Pengembangan Teknologi Pedesaan (NGO), Indonesia
Ltd.	Private company limited by shares
MoU	Memorandum of Understanding
NGO	Non Governmental Organisation
NTU	Standardized Degree of Turbidity
OTM	Organic Total Solids
O&M	Operation and Maintenance
PE-HD	or HDPE – High Density Polyethylene
pH	pH is a measure of the acidity or basicity of a solution
PHAST	Participatory Hygiene and Sanitation Transformation
PhP	Philippines Pesos (currency)
PVC	Polyvinyl Chloride
RPA	Rapid Participatory Assessment
SANIMAS	Sanitation by Neighbourhoods, Community-Based Sanitation Project, 2001-04 financed by a trustfund from AusAID managed by WSP East Asia. Ongoing as national sanitation programme under multi-finance scheme (Ministry of Public Works, local level authorities and beneficiaries)
SDSI	Sustainable Development Strategy Institute
SENA	Chinese State Environmental Protection Administration
SME	Small and Medium Entities
SS	Suspended Solids
TOC	Total Organic Carbon
TS	Total Solids
UASB	Upflow Anaerobic Sludge Blanket
UNDP-HDR	The Human Development Report is an annual milestone publication by the United Nations Development Programme
UNICEF	United Nations Children's Fund (originally United Nations International Children's Emergency Fund)
UN-WWDR	United Nations World Water Development Report
UK	United Kingdom
US	United States
US EPA	United States Environmental Pollution Agency
UV	Ultraviolett radiation
VFA	Volatile Fatty Acids
VIP	Ventilated Improved Pit Latrine
VS	Volatile Solids
WaterGAP	Water, Global Assessment and Prognosis (Modelling Tool)
WEDC	Water, Engineering and Development Centre, Loughborough University, United Kingdom
WEFTEC	Water Environment Federation's annual Technical Exhibition and Conference
WHO	World Health Organisation
WSP	Water and Sanitation Program
WWAP	World Water Assessment Programme
ZP	Zilla Parishad (Indian Government Admistration on District level)
ZUT	Zhejiang University of Technology

14.1 Geometric formulas

Table 45:
Geometric formulas

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

14.2 Energy requirement and cost of pumping

	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 46:
Energy requirement and cost of pumping

C4 = A4 / B4

G4 = 9.81 x (D4 + E4) x C4 / F4 / 3600

I4 = B4 x G4 x 365 x H

14.3 Sedimentation and flotation

The performance of a domestic-wastewater settler is sufficient when the effluent contains less than 0.2ml/l settleable sludge after a 2h jar test.

The general formula for calculating the surface area for floatation and sedimentation tanks is:

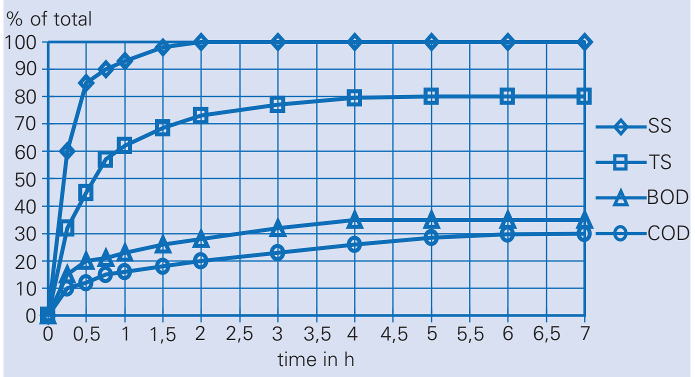
Water surface $[m^2]$ = water volume $[m^3/h]$ /
slowest settling (floatation) velocity [m/h].

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 $[m^2]$ = flow $[m^3/s]$ / 0.3 [m/s], or
Area $[m^2]$ = flow $[m^3/h]$ / 1000 [m/h]



Appendix_1:
Removal rates in settling tests of domestic wastewater

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 $\mathrm{CODKMnO_4}$). 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.

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