TECHNOLOGICAL MATRIX

Decision Making Tool for Wastewater Treatment Technology

UNEP

GPA Global Programme of Action for the Protection of the Marine Environment from Land-based Activities
Global Wastewater Initiative

IWA the international water association

ACKNOWLEDGEMENT

JOINT FOREWORD

(EWA Executive Director +UNEP Executive Director)

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1 Introduction

1.1 What is the Wastewater Technology Matrix?

The purpose of the *Wastewater Technology Matrix* is to provide decision makers and donors in low and middle income countries with **a decision-making tool for selecting appropriate wastewater systems in urban areas**.

This guidance document provides the necessary background and user instructions. The tool itself is an excel file with attached pdf-factsheets. In this document the words *wastewater management* and *sanitation* will be used interchangeably, with both words referring to domestic effluent consisting of *blackwater* or *excreta*, sometimes including greywater (kitchen and bathing wastewater) and/or stormwater.

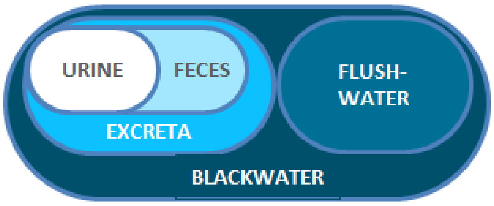

Figure 1, definition of difference between excreta and blackwater.

1.2 Who is this tool for?

The Wastewater Technology Matrix is mainly for decision makers that at some level are involved – or have interest in – wastewater or sanitation planning, for example those who work for local authorities, utilities or non-governmental organisations. **The tool has been especially developed with non-technical people**, **with no or little knowledge on wastewater or sanitation, in mind.** The matrix thus serves as a starting point to narrow down the technology options, before consulting relevant stakeholders and technicians.

1.3 WHY IS THIS TOOL NEEDED?

The world is currently facing a water quality crisis caused by continuous population growth, industrialization, food production practices, increased living standards and poor water use and wastewater management strategies. **Improving wastewater management is essential for improving the quality of both the surrounding environment and public health.**

In urban areas of industrialised countries, the common practice until now has been to collect wastewater and transport it to a centralized municipal treatment plant. After treatment the water is discharged into a water body. This system has many inherent problems, including very high costs, not only of investment, but also of operation and maintenance because of the complex piped distribution systems. Furthermore, this system is even more costly because of the high energy consumption for treatment, and large volumes of water required for flushing and transporting human excreta.

When designing sanitation systems, instead of only replicating this highly engineered wastewater treatment system that has not been successful in many developing world contexts, **it is crucial to consider the entire spectrum of wastewater solutions.** This is – in addition to the disadvantages of the conventional sewer systems already mentioned – because of the following four aspects:

1. Resource recovery and closed loop approaches are becoming more and more important, including for the wastewater sector. This makes it essential for decision makers to consider desirable outputs of the system at an early stage, something this tool allows for by taking the entire sanitation chain into account (see Figure 2). The emerging trend for new systems is an increasing degree of nature-based, decentralised systems. **Wastewater, when properly managed, is a valuable resource from which water can be recycled, and nutrients and energy recovered.**

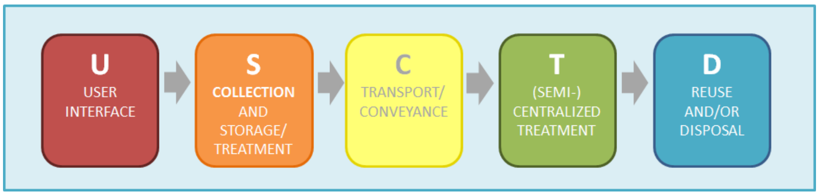

FIGURE 2, THE ENTIRE SANITATION CHAIN WITH EACH OF ITS FUNCTIONAL GROUPS.

2. Cities are growing faster and faster with urban population expected to reach 5.2 billion in 2050 compared to 2.6 billion in 2010. **Developing countries need to respond to this challenge faster than developed countries have done in the past, and thus new approaches are needed** (Boston consulting group, 2014). Conventional systems take years to construct and must be designed for a certain load. Meanwhile, decentralised systems offer a more modular approach, which is easier to adjust and add more users to, and thus often would be more appropriate in rapidly growing urban areas.

3. Access to sanitation contributes to urban areas socio-economic development. **The rate of return for sanitation investments is estimated to be more than 5 USD for each spent** (WHO 2012, World Bank 2013), and evidence shows that the benefits Include improvements in:

- Public health
- The natural environment
- Education
- Economic development
- Social outcomes
- Gender equality
- Poverty alleviation

4. Local conditions will always be significant factors in deciding a specific technology's appropriateness, for example if the soil conditions allow for infiltration of water, or if there is a reliable source of electricity for powering treatment. In addition, sanitation needs to be demand-driven based on communities' needs and preferences to ensure long term sustainability. **This tool allows the user to provide both local conditions and priorities to serve as basis for ranking the different relevant technology systems.** Existing solutions should also be taken into account.

Getting the complete overview of existing solutions to decide which would be most relevant for a given situation can be an extremely complex and time consuming process for decision makers. **The Wastewater Technology Matrix acts as an efficient and user-friendly filtering process – a multi-criteria analysis that takes environmental, social and economic aspects into account**, and ranks and presents the most relevant technologies based on the user's inputs. The matrix furthermore links to fact sheets with more information of each of the technologies and serves as a basis for further decision making. The tool also allows for advanced users to add technologies to the matrix, making it a living document.

This tool is an increasingly valuable instrument as awareness about high returns from investments in sanitation are growing, as well as the growing acknowledgement of how **sanitation is essential to development as well as a crucial cornerstone of the liveable and resilient city.**

WHY IS THIS TOOL IMPORTANT?

- The wastewater paradigm until now has been centralised sewer systems. However, these sewer systems are often not the optimal solution, especially in low and middle income countries.
- Investing in sanitation has a very high rate of return of investment (minimum 5 USD), but as costly centralised sewers are often seen as the only option, no investments are made.
- As resource recovery is becoming increasingly important, it must be taken into account that different wastewater systems provide various options for and degrees of resource recovery.
- Rapid urbanisation makes modular systems increasingly relevant, and already today 40% of the world's population has on-site (non-sewer) systems.
- Local conditions as water scarcity, cultural aspects and priorities of users, needs to be considered when deciding on technologies.

The entire spectrum of wastewater solutions should be taken into account, but getting the overview is a complicated and time consuming task. This Wastewater Technology Matrix, based on the users input on local conditions and priorities, presents the most relevant technologies.

1.4 How to use the results

As previously highlighted, the purpose of the Wastewater Technology Matrix is to act as a filter within a broader decision-making process. The result is an indication of the 5-10 most relevant sanitation systems for a given locality, and thus it provides valuable input to the process of select a system in an urban community. **The tool is meant to act as a step within the process of decision making as described in *Sanitation 21*.** Sanitation 21 presents a new, integrated approach towards sanitation planning that not only considers infrastructure, but sees sanitation as a service and consider environmental concern, poverty, equity, land ownership and the wider political economy (Parkinson et al., 2014). **An overview of the steps in Sanitation 21, as well as indicated clearly what part that is covered by this tool can be seen in Figure 3.**

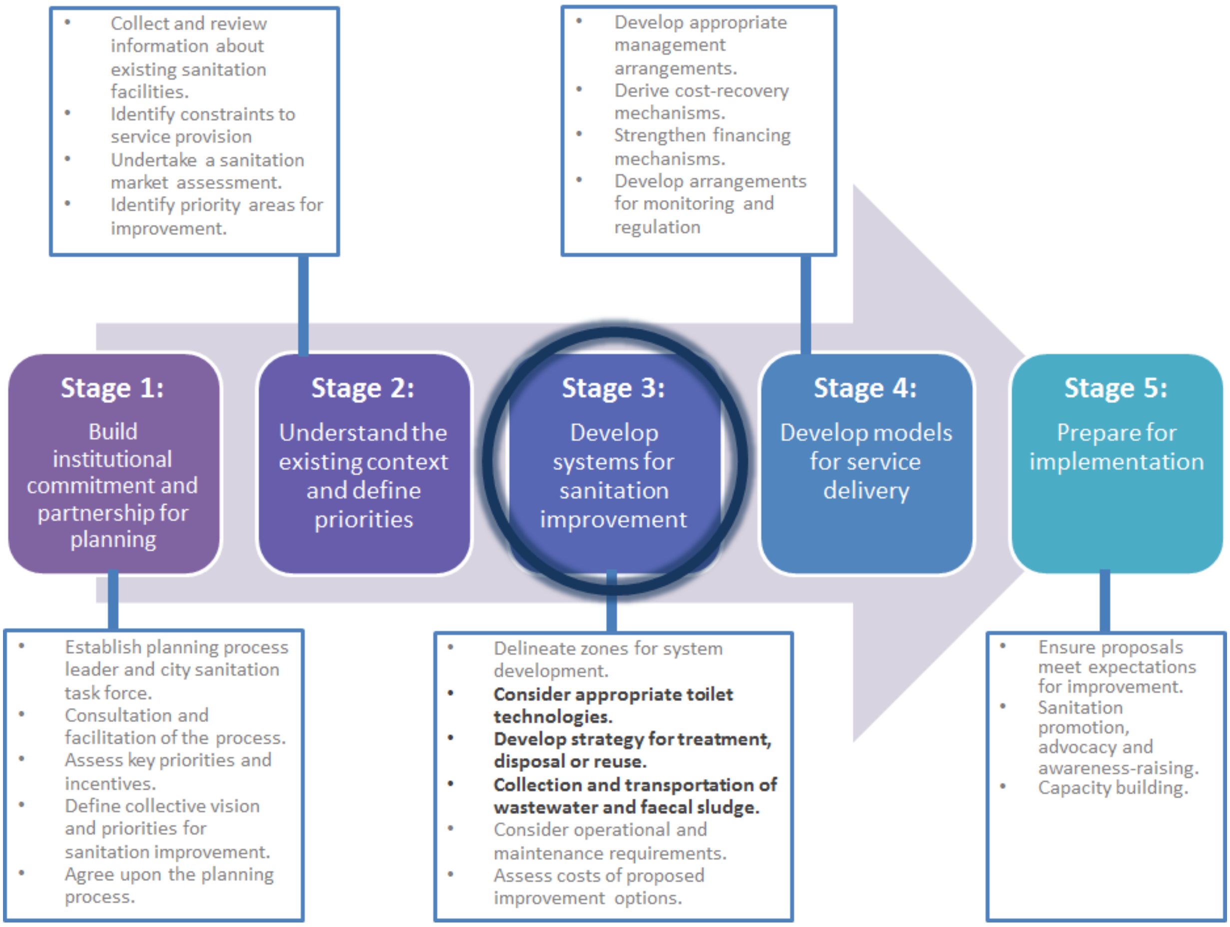

Figure 3 Sanitation 21 and how this tool fits within step 3, the relevant sub-part is highlighted with bold text.

The main goals of Sanitation 21 are:

- *A vision of the need for sanitation improvements which is shared between different stakeholders within the city.*
- *A clear definition of realistic priorities for improvements across the city*
- *A comprehensive sanitation development plan that corresponds to users' demands and different physical and socio-economic conditions within the city*
- *A supportive enabling environment with regards to policy and governance for promoting the implementation of proposed components of the plan*
- *Capacity building actions required for ensuring that facilities and infrastructure are adequately managed and maintained.*

2 About the matrix

2.1 The principles of the tool

The Wastewater Technology Matrix is based on the ***Compendium of Sanitation Systems and Technologies*** (Tilley et al., 2014) by Eawag, IWA and WSSCC (Water Supply and Sanitation Collaborative Council). **This compendium provides a clear overview of the relevant sanitation technologies and systems, including detailed fact-sheets for each of the technologies.** However, for a decision maker with limited knowledge of sanitation and wastewater, reading the entire compendium to identify relevant technologies would be overwhelming and still very time consuming. The Wastewater Technology Matrix helps by significantly narrowing down the options and thus allows the decision-making process to be considerably more efficient. **The technologies found in the matrix, as well as the colour codes and terms are identical with the ones found in the compendium, and the results page links to the technology fact sheets**.

An example of a suggested system from the compendium can be seen in Figure 4, and this figure also gives a good starting point for understanding the basic principles of the tool. The flow of human waste, and/or wastewater is from left to right where each step is a functional group with a colour code and a letter, for example the first functional group is “User interface” with the letter U and the colour red. As can be seen in the figure most of the system options involve a separation to both a sludge and an effluent (water) phase that needs to be treated separately.

The Wastewater Technology Matrix is a tool that performs a ***Multi criteria analysis, or MCA,*** on the different sanitation technologies. MCA is a family of methods to compare alternative options and to identify the best performing one, on the basis of multiple factors. The evaluation is based on a number of *criteria* which consist of more detailed *indicators*, that each individually indicates the performance of the alternative options. The starting point is to set up **an evaluation matrix, which contains the possible alternatives and the criteria against which they have to be evaluated** (see example of matrix set up in Figure 5). As evaluation criteria may have different relative importance, weights are usually assigned to each criterion to be included into the evaluation.

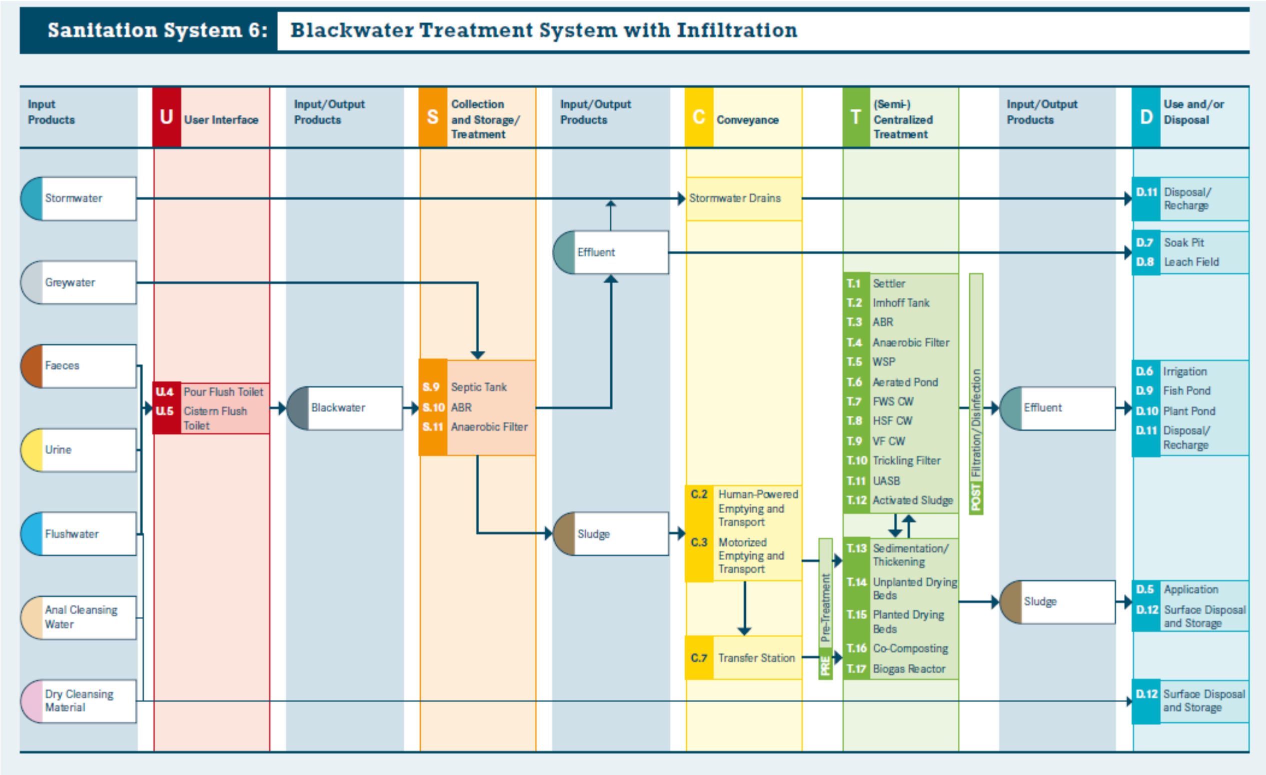

FIGURE 4, EXAMPLE OF SUGGESTED SYSTEM FROM THE COMPENDIUM

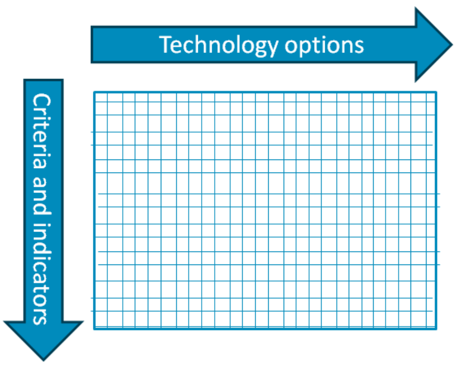

FIGURE 5, EXAMPLE OF AN MULTI CRITERIA ANALYSIS MATRIX.

Multi criteria methodologies are increasingly becoming popular in decision making processes with multiple objectives and sometimes also with several stakeholders. Nevertheless – and as already mentioned as an important point of this matrix – solving a multi criteria problem often does not mean to find an optimum solution, but to facilitate discussion and understanding of the different alternatives towards the finding of the most suitable solution.

2.2 THE STRUCTURE OF THE TOOL

The tool is developed to be both intuitive and user friendly, which means that few instructions are needed. However, **to understand the processes underlying the programme between the input and the output, Figure 6 provides an overview**. For more details and argumentations regarding specific ratings and exclusions, please consult Chapter 4: Details, Assumptions and Advanced settings. As the programme is made in excel it is very transparent, easy to use and requires no coding skills for the user to get below the surface and actually see how the programme works.

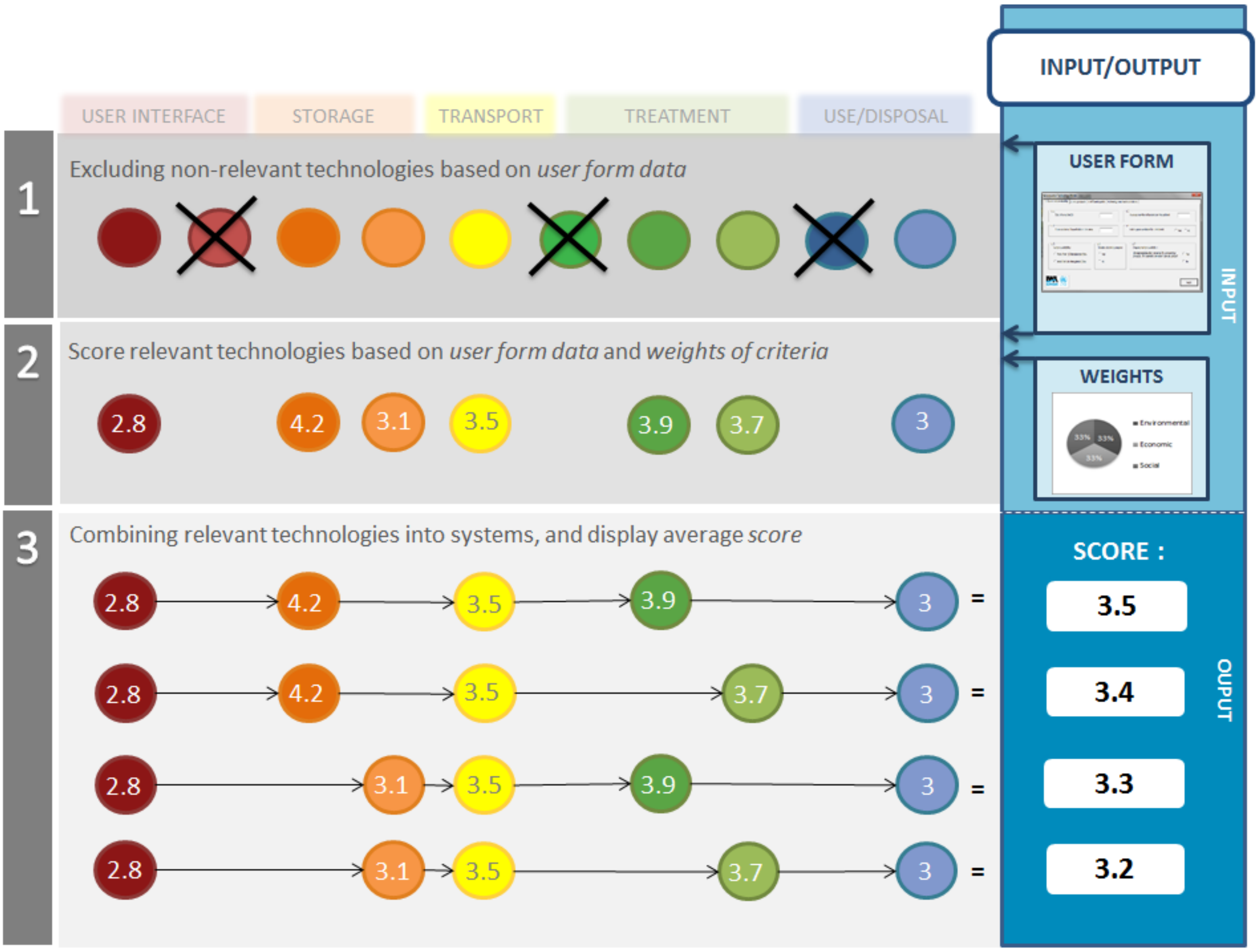

FIGURE 6, AN OVERVIEW OF THE PROCESSES UNDERLYING THE MATRIX. THE INPUT FROM THE USER FORM IS USED IN STEP 1 TO EXCLUDE CERTAIN TECHNOLOGIES, AND IN STEP 2 TO RATE THEM. THE SCORE OF EACH TECHNOLOGY IS FURTHERMORE BASED ON THE WEIGHTS, WHICH ARE ALSO PROVIDED AS INPUT BY THE USER. THE PROGRAMME THEN, IN STEP 3, COMBINES THE TECHNOLOGIES INTO SYSTEMS AND DISPLAY THEIR AVERAGE SCORE IN AS OUTPUT ON THE RESULTS PAGE.

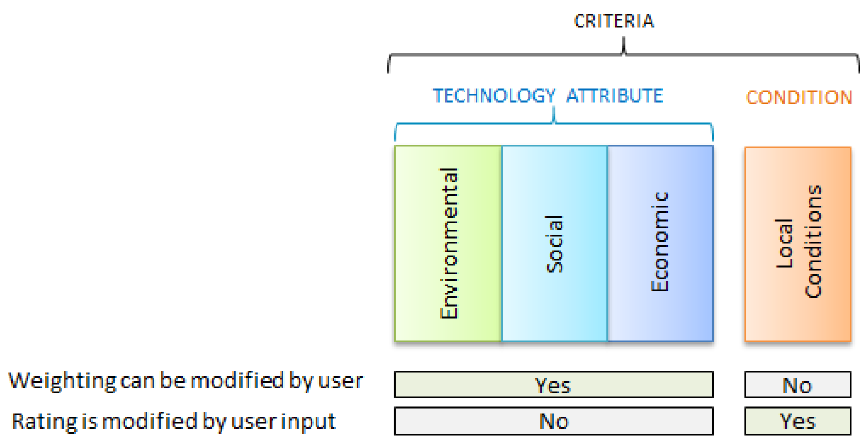

FIGURE 7 AN OVERVIEW OF THE RELATION BETWEEN CRITERIA, CONDITIONS AND TECHNOLOGY ATTRIBUTES – AND HOW THESE CAN BE MODIFIED BY USER INPUT

The tool is based on a multi-criteria analysis with regards to environmental, social and economic aspects. Each of these categories are called *criteria* and consist of multiple *indicators* that has a rating from 1 to 5. One of the indicators of the economic criteria would for example be "*what are the capital costs*?", where 5 is very low and 1 is very high. In addition, input from the user on local conditions provides fourth criteria (see Figure 7. To make it intuitive and mathematically clear, only the three criteria, environmental, social and economic, or the so-called technology attributes, will be displayed throughout the tool. This means that the user changes the technology attributes only by changing their weight. And the last criterion, the local conditions – is a condition, not a technology attribute – and is therefore only changed by direct input data, while the weight remains constant.

If a technology is excluded it will get the score 0, and any sanitation system which includes this technology will also be 0. In the demo version, only 18 sanitation systems are possible. For an overview of the possible technology lines, see Figure 8 on the next page.

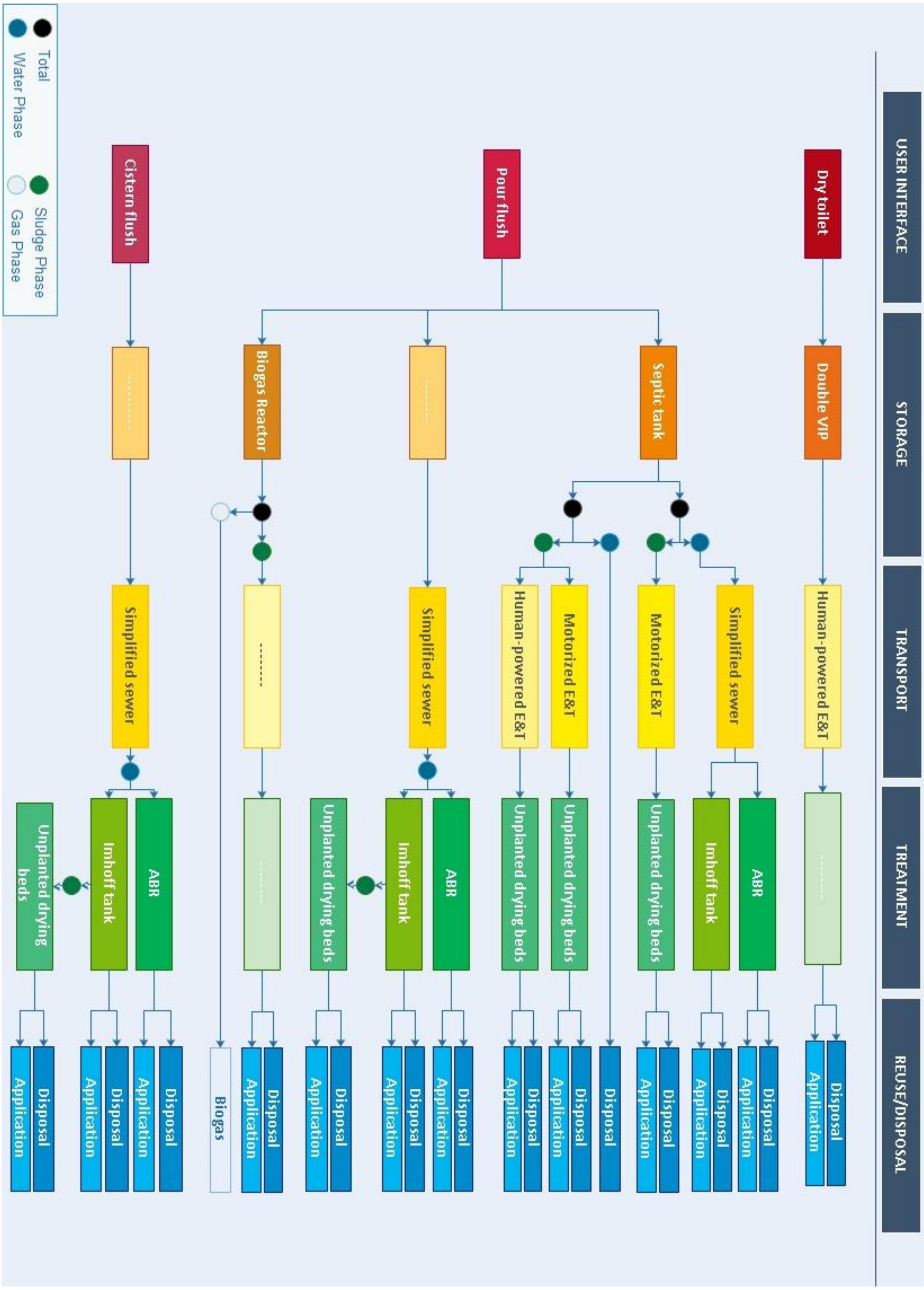

FIGURE 8, OVERVIEW OF TECHNOLOGIES AND POSSIBLE COMBINATIONS IN THIS DEMO VERSION OF THE WASTEWATER TECHNOLOGY MATRIX. THIS VERSION ASSUMES THAT IF ONE FRACTION IS DISPOSED OR APPLIED, THE OTHER ONE IS AS WELL. IN TOTAL THIS GIVES 18 SANITATION SYSTEM OPTIONS.

3 STEP BY STEP USERGUIDE

3.1 HOW TO OPEN THE TOOL

The Wastewater Technology Matrix is a Microsoft® Excel-based Tool. It is compatible with 2007, 2010 and 2013 versions of Excel. The tool itself is in a zipped folder because of the attached pdfs. **To have the links to the pdfs to function, please extract the entire folder before opening the excel file.**

The Tool contains macros which must be enabled in order for the Tool to function. Therefore, when you open the Tool, you will be requested to enable macros before the '1. START' page will be displayed. If macros are disabled, which they normally are the first time, you will receive a security warning near the top of the page, and only an "Enable Macros" sheet will be visible. Instructions in the tool will explain how to enable macros. These instructions can also be found in Appendix 1.

3.2 START SHEET

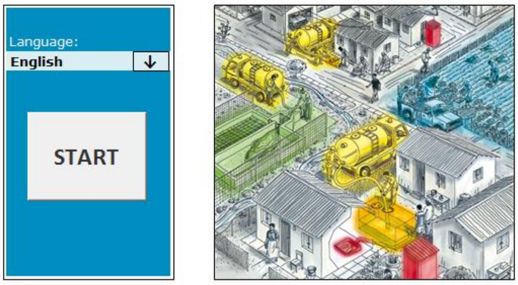

FIGURE 9, HOW THE 1.START SHEET LOOKS. BY PRESSING THE 'START'BUTTON YOU START THE TOOL.

To begin the Wastewater Technology Matrix tool, simply click the *'Start'* button found on the *'1.START'* sheet, and the user form will be displayed. Figure 9 shows what the '1.START' sheet looks like, and an example of a page in the user form can be seen in Figure 10. It will be possible in later versions to change the language of the entire visible part of the tool, as well as adding more languages, via the *'1.START'* sheet. For now, in the demo version, only English is available.

By answering questions in the user form you provide input to the tool about the local conditions. The results of the tool will never be better than the input provided, so try to answer as many questions as accurately as possible. The option “unknown” should only be used if the question is impossible to answer. There are 4 tabs in the user form, Tab ‘*3: Effluent quality’* does not need to be answered as this function is not fully developed yet. For every time you press a *‘Next’* button your data is saved.

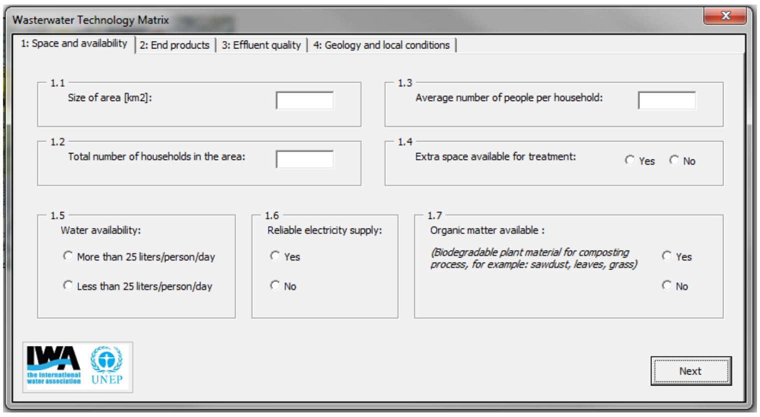

FIGURE 10, EXAMPLE OF HOW THE USER FORM LOOKS. EVERY TIME A ‘NEXT’ BUTTON IS PRESSED THE DATA ENTERED IS SAVED.

After clicking *‘Finish’* you will automatically be brought to the form for weighting the criteria. Each of the three criteria (Environmental, Economic and Social) is multiplied with a weight in the MCA. These weights can be adjusted by answering the three questions in this user form. Again, please consider that these answers will be important for the accuracy of your results and you should take your time and care to make sure you have applied the correct weighting. Pressing the button ‘*Ok’*, will bring you to the result sheet.

3.3 RESULTS SHEET

In the result sheet, data is sorted in descending order of score, according to the Multi Criteria Analysis (MCA) Matrix calculations. For an explanation of the results interface, please see Figure 11. Each row represents one *sanitation system*, or sanitation chain of combination of technologies. Each column represents each of the five technology steps or *functional groups*. In most sanitation systems there will at some point be a separation of the water and sludge phase and each phase must be treated individually. The results page illustrates this by splitting the row into an upper line (**water phase/blue**) and lower line (**sludge phase/green**). The *main score* for each sanitation system is represented in column labelled *"SCORE"* with a number (high-low) with both a corresponding colour code (green-red), and also a bar (long-short). The minimum and maximum of each of these scales are 1 and 5, respectively.

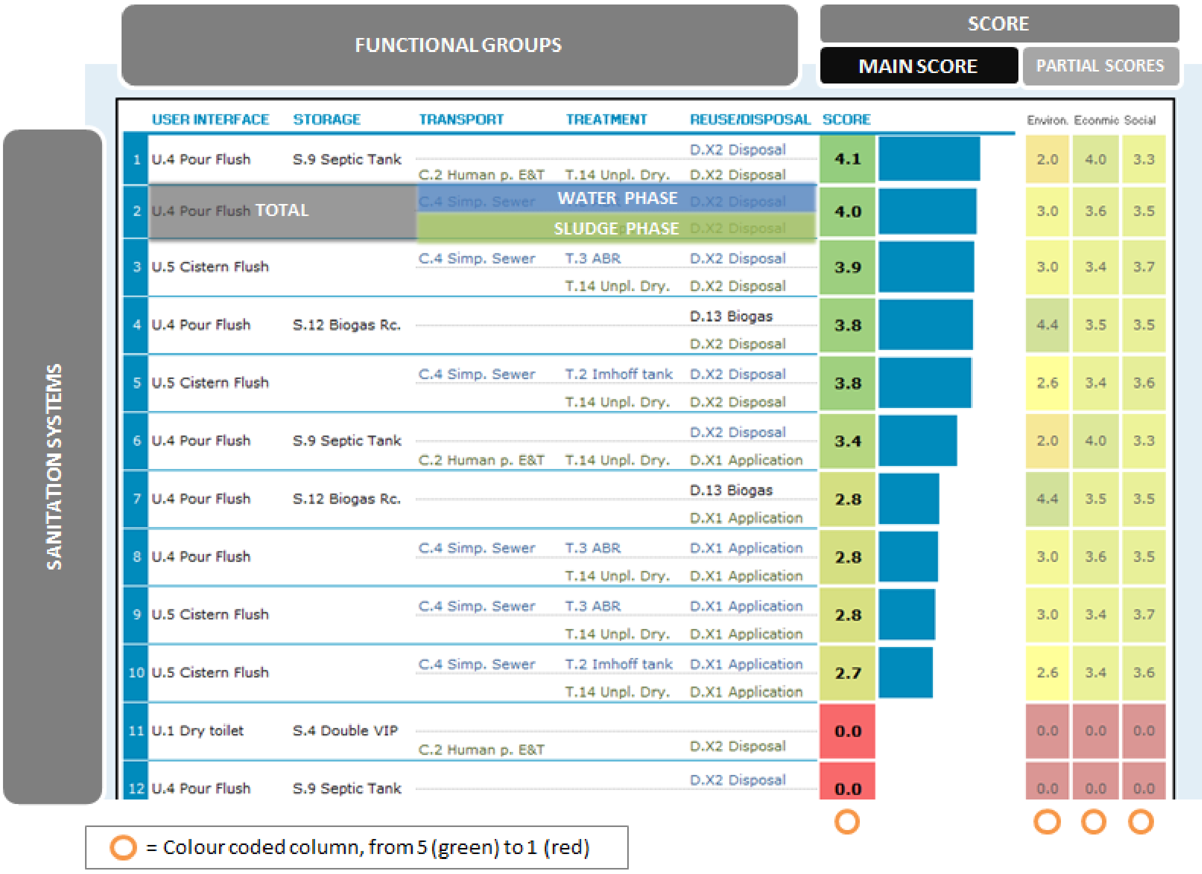

Figure 11, explanation of the user interface on the results sheet. The score is divided into a main and a partial (unweighted for each criteria) score, all colour coded. Note that for most sanitation systems there will be a separation into a water and sludge phase that each must be treated differently.

To the right of the main score the *partial score* can be seen. The partial score display the unweighted score for each of the criteria. Again a colour code from 1 (red) to 5 (green) is used on each cell.

By clicking each of the technologies a pdf document will open with details regarding:

- Design considerations
- Appropriateness
- Health aspects/acceptance

- Operation and management
- List of pros and cons
- List of references and further reading.

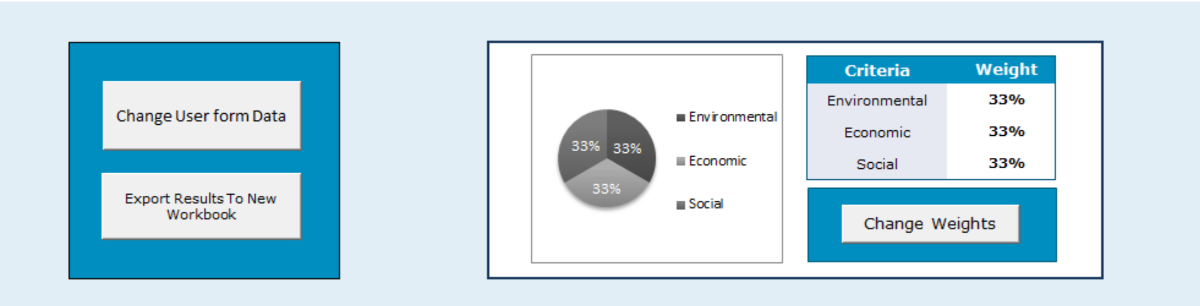

FIGURE 12, INTERFACE BELOW THE RESULTS WITH BUTTONS FOR CHANGING INPUT (BOTH WEIGHTS AND USER FORM) AND EXPORTING THE RESULTS.

Below the results the part in Figure 12 can be seen, this part allows for editing inputs and exporting outputs. To open the user form again to edit the input data, or to export the data to another workbook – simply click the buttons *'Change User form Data'* or *'Export Results to New Workbook*', respectively. To the right of these buttons the applied weighting can be seen both percent-wise and as a pie chart. A button below named *'Change Weights'* can be used to re-open and edit the criteria. Below these buttons the existing input data from the user form are displayed.

3.4 MCA OVERVIEW SHEET

This sheet shows the entire MCA Matrix and its calculations. The sheet is hidden for the average users, but can be unhidden by pressing a button atat the bottom of the '*2.Results'* sheet. The MCA is divided in three criteria, plus the criteria for the local conditions (for overview see Figure 7). For each criterion there are numerous indicators, for example "Effluent Nitrogen quality". Each indicator is rated 1-5 based on a literature review as well as expert's consultation, and cannot be changed by the user. The list of indicators will be expanded in later versions. If the pre-screening eliminates a technology a red 'X' and a text explanation will be displayed in the '*Exclusion Field*'. For example if too little water is available, all *User Interface* with a *'U.5 Cistern Flush'* toilet that requites large amounts of flush water for transportation will be eliminated. The colour of each cell indicates its value from high to low (green to red).

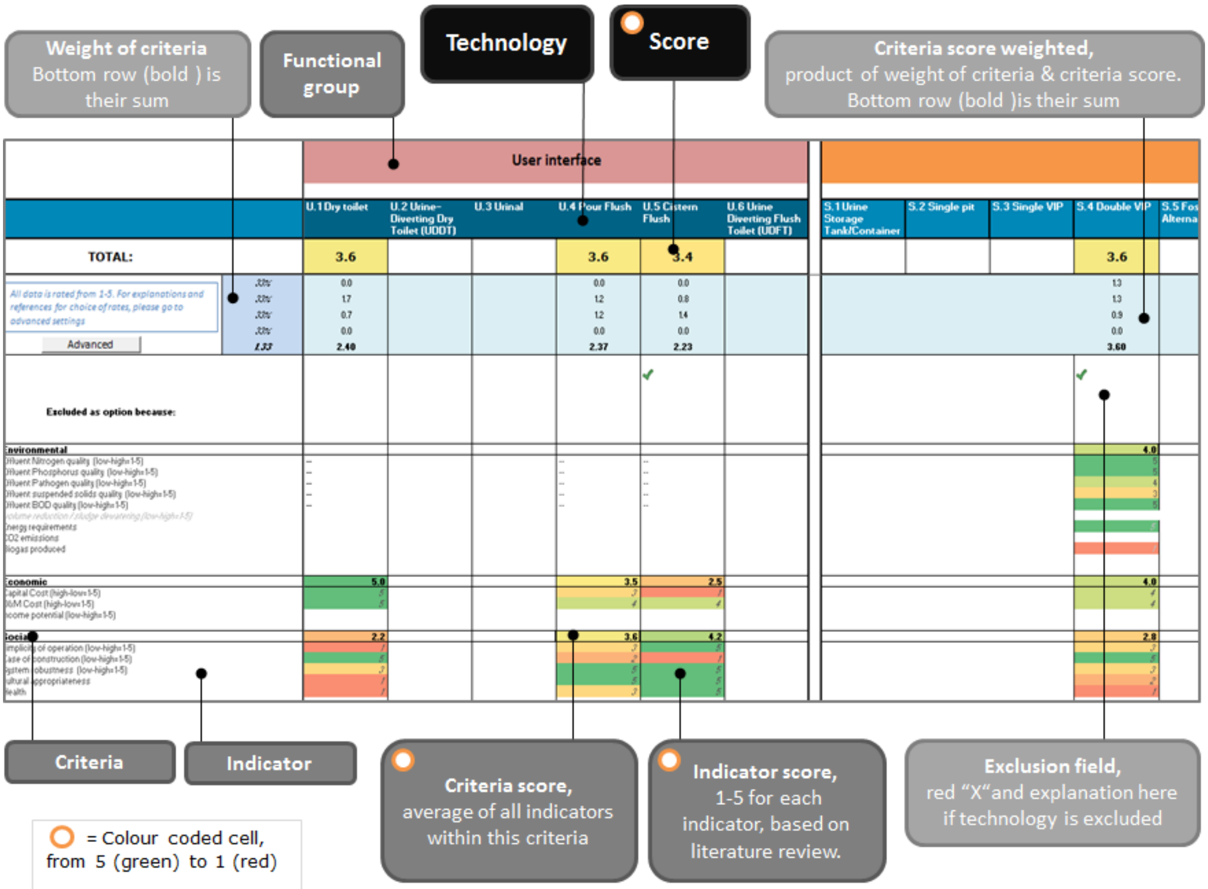

Figure 13 explanation of each of the fields in the multi criteria analysis matrix sheet. A darker colour of explanation box, means higher importance of the field

Through this sheet it is also possible, if the user is interested, to access the *advanced settings* of the tool. This allows the user to:

- See reasoning behind matrix rating, based on literature, including references
- Add technologies to the matrix
- Add languages to the entire tool
- Details behind calculations

Be aware that some of these settings can change the entire tool permanently and should be only used if necessary. For details on the advanced settings, please consult Chapter 4.

4 DETAILS, ASSUMPTIONS AND ADVANCED SETTINGS

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Will be available in final version.

5 LINK TO RELEVANT LITERATURE AND TOOLS.

Online compendium of Sanitation Systems and Technologies

Including link for downloading complete pdf version:

http://ecompendium.sswm.info/

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More links will be available in final version.

6 REFERENCES

Boston Consulting Group (2014), Urban sanitation: Why a portfolio of sanitation solutions is needed. Published December 2014. Retrieved February 26, 2015. Link: http://www.bcg.nl/documents/file178928.pdf

Luethi, C., Morel, A., Tilley, E., Ulrich, L. (2011). *Community-Led Urban environmental sanitation planning: CLUES - Complete guidelines for decision-makers with 30 tools*. Swiss Federal Institute of Aquatic Science and Technology (Eawag), Dübendorf, Switzerland, WSSCC, Geneva, Switzerland and UN-HABITAT, Nairobi, Kenya

Parkinson, J., Lüthi, C. Walther D. (GIZ). (2014) *Sanitation21 - A Planning Framework for Improving City-wide Sanitation Services*. IWA, Eawag-Sandec, GIZ.

Tilley, E., Ulrich, L., Lüthi, C., Reymond, Ph., Zurbrügg, C. (2014). *Compendium of Sanitation Systems and Technologies - (2nd Revised Edition).* Swiss Federal Institute of Aquatic Science and Technology (Eawag), Duebendorf, Switzerland

WHO (2012) *Global costs and benefits of drinking-water supply and sanitation interventions to reach the MDG target and universal coverage*, WHO/HSE/WSH/12.01. World Health Organization. Online version retrieved February 26, 2015. Link: http://www.who.int/water_sanitation_health/publications/2012/globalcosts.pdf

World Bank (2013) *Infographic: What's a Toilet Worth?* Published: August 30, 2013. Retrieved February 26, 2015. Link: http://www.worldbank.org/en/news/feature/2013/08/30/whats-a-toilet-worth-infographic

Appendix 1: Enable Macros

Normally when you open the tool for the first time you will only be able to see a "Enable Macros" sheet, as well as a security warning (usually as a yellow bar at the top of the screen).

A)

If you see the Security Warning, as also described in the tool itself on the "Enable Macros " sheet, either:

1. Select 'Always trust macros from this publisher' and 'Enable Macros'.
2. or select 'options' and then 'Trust all documents from this publisher' and 'ok'.
3. or select 'enable this content'. Then click 'Yes' when asked, 'Do you want to make this file a trusted document'.

B)

If the security warning from Excel is not displayed, please follow the relevant directions for Excel 2007 or 2010/2013, respectively:

To enable macros when using excel 2007 version:

1. Go to the top left corner and select the Round Offi ce button.
2. Select 'excel options' near the bottom right corner.
3. Select 'Trust Center' and then 'Trust Center Settings'.
4. Select 'Message Bar' and from the options, select 'Show the Message Bar in all applications when content has been blocked'.
5. Select 'Macro Settings' and from the options, select 'Disable all macros with notifi cation'.
6. Click 'ok' twice.
7. Close the fi le and re-open it. There is no need to save the fi le prior to closing when prompted. When you open the fi le, you will receive a security warning. Select 'options', then 'Trust all documents from this publisher' and 'ok'. This will allow all the features of the Tool to be fully active.

To enable macros when using Excel 2010/2013 version:

1. Go to the top left corner and select 'File'.
2. Select 'options'.
3. Select 'Trust Center' and then 'Trust Center Settings'.
4. Select 'Message Bar' and from the options, select 'Show the Message Bar in all applications when active content, such as ActiveX controls and macros, has been blocked'.
5. Select 'Macro Settings' and from the options, select 'Disable all macros with notification'.
6. Click 'ok' twice.
7. Select 'enable this content' (within the home tab). Then click 'Yes' when asked, 'Do you want to make this file a trusted document'. This will allow all the features of the Tool to be fully active.

For help, please contact *MarieR.Sagen@iwahq.org*

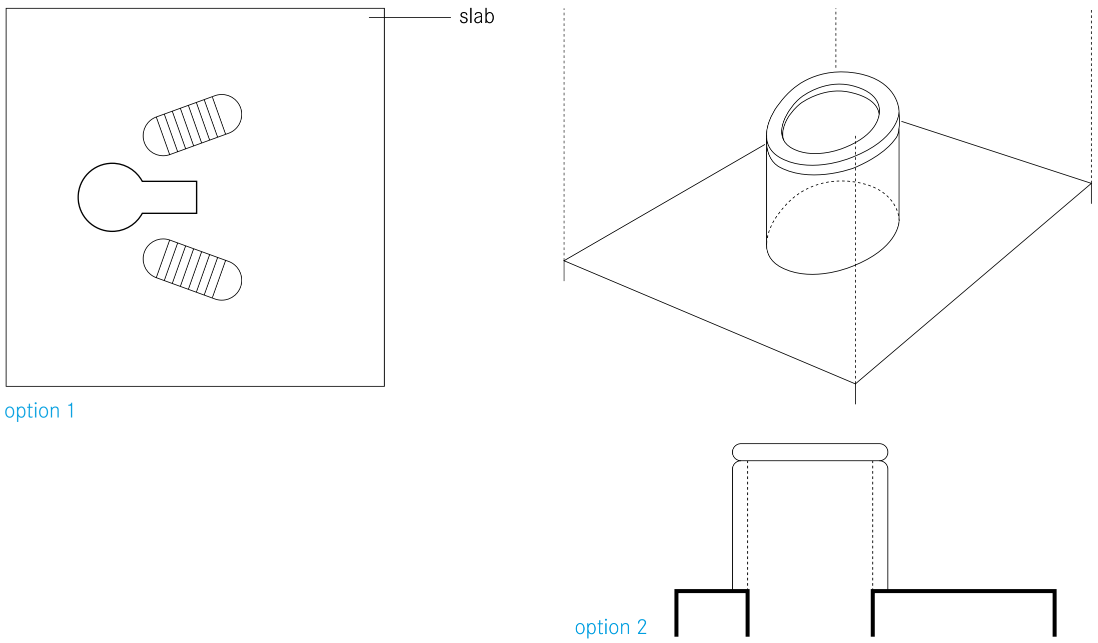
APPENDIX 2: FACTSHEETS

U.1 Dry Toilet

Applicable to:
Systems 1, 2

Inputs: Faeces Urine
(Anal Cleansing Water) (Dry Cleansing Materials)

Outputs: Excreta (+ Anal Cleansing Water)
(+ Dry Cleansing Materials)



A dry toilet is a toilet that operates without flushwater. The dry toilet may be a raised pedestal on which the user can sit, or a squat pan over which the user squats. In both cases, excreta (both urine and faeces) fall through a drop hole.

In this compendium, a dry toilet refers specifically to the device over which the user sits or squats. In other literature, a dry toilet may refer to a variety of technologies, or combinations of technologies (especially pits).

Design Considerations The dry toilet is usually placed over a pit; if two pits are used, the pedestal or slab should be designed in such a way that it can be lifted and moved from one pit to another.
The slab or pedestal base should be well sized to the pit so that it is both safe for the user and prevents stormwater from infiltrating the pit (which may cause it to overflow). The hole can be closed with a lid to prevent unwanted intrusion from insects or rodents.
Pedestals and squatting slabs can be made locally with concrete (providing that sand and cement are available). Fibreglass, porcelain and stainless steel versions may also be available. Wooden or metal moulds can be used to produce several units quickly and efficiently.

Appropriateness Dry toilets are easy for almost everyone to use though special consideration may need to be made for elderly or disabled users who may have difficulty. When dry toilets are made locally, they can be specially designed to meet the needs of the target users (e.g., smaller ones for children). Because there is no need to separate urine and faeces, they are often the simplest and physically most comfortable option.

Health Aspects/Acceptance Squatting is a natural position for many people and so a well-kept squatting slab may be the most acceptable option.
Since dry toilets do not have a water seal, odours may be a problem depending on the Collection and Storage/ Treatment technology connected to them.

Operation & Maintenance The sitting or standing surface should be kept clean and dry to prevent pathogen/disease transmission and to limit odours.
There are no mechanical parts; therefore, the dry toilet should not need repairs except in the event that it cracks.

Pros & Cons

+ Does not require a constant source of water
+ Can be built and repaired with locally available materials
+ Low capital and operating costs
+ Suitable for all types of users (sitters, squatters, washers, wipers)
- Odours are normally noticeable (even if the vault or pit used to collect excreta is equipped with a vent pipe)
- The excreta pile is visible, except where a deep pit is used
- Vectors such as flies are hard to control unless fly traps and appropriate covers are used

References & Further Reading

_ Brandberg, B. (1997). *Latrine Building. A Handbook for Implementation of the Sanplat System.* Intermediate Technology Publications, London, UK. pp. 55-77.
(Describes how to build a squatting slab and the moulds for the frame, footrests, spacers, etc.)

_ CAWST (2011). *Introduction to Low Cost Sanitation. Latrine Construction. A CAWST Construction Manual.* Centre for Affordable Water and Sanitation Technologies (CAWST), Calgary, CA.
Available at: www.cawst.org
(Very detailed construction manual for different slab designs)

_ Morgan, P. R. (2007). *Toilets That Make Compost. Low-Cost, Sanitary Toilets That Produce Valuable Compost for Crops in an African Context.* Stockholm Environment Institute, Stockholm, SE.
Available at: www.ecosanres.org
(Excellent description of how to make support rings and squatting slabs (pp. 7-35) and pedestals (pp. 39-43) using only sand, cement, plastic sheeting and wire)

_ Morgan, P. R. (2009). *Ecological Toilets. Start Simple and Upgrade from Arborloo to VIP.* Stockholm Environment Institute, Stockholm, SE.
Available at: www.ecosanres.org

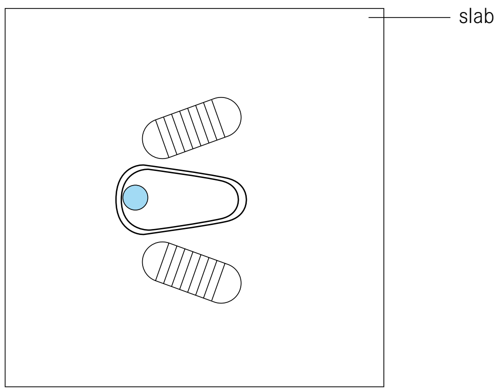
_ Reed, B. (2012). *An Engineer's Guide to Latrine Slabs.* WEDC, Loughborough University, Leicestershire, UK.
Available at: wedc.lboro.ac.uk/knowledge/booklets.html
(Comprehensive guide with key information and checklists for design, construction and maintenance)

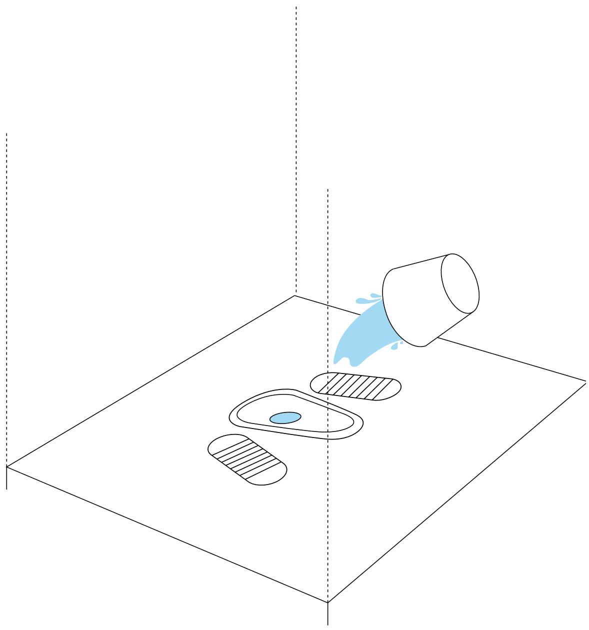
U.4 Pour Flush Toilet

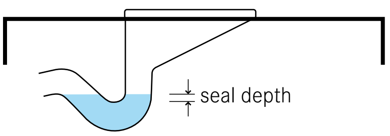
Applicable to:
Systems 1, 3, 5-8

Inputs: Faeces Urine Flushwater (Anal Cleansing Water)(Dry Cleansing Materials)

Outputs: Blackwater







A pour flush toilet is like a regular Cistern Flush Toilet (U.5) except that the water is poured in by the user, instead of coming from the cistern above. When the water supply is not continuous, any Cistern Flush Toilet can become a pour flush toilet.

Just like a Cistern Flush Toilet, the pour flush toilet has a water seal that prevents odours and flies from coming back up the pipe. Water is poured into the bowl to flush the toilet of excreta; approximately 2 to 3 L is usually sufficient. The quantity of water and the force of the water (pouring from a height often helps) must be sufficient to move the excreta up and over the curved water seal.
Both pedestals and squatting pans can be used in the pour flush mode. Due to demand, local manufacturers have become increasingly efficient at mass-producing affordable pour flush toilets and pans.

Design Considerations The water seal at the bottom of the pour flush toilet or pan should have a slope of at least 25°. Water seals should be made out of plastic or ceramic to prevent clogs and to make cleaning easier (concrete may clog more easily if it is rough or textured). The S-shape of the water seal determines how much water is needed for flushing. The optimal depth of the water seal head is approximately 2 cm to minimize the water required to flush the excreta. The trap should be approximately 7 cm in diameter.

Appropriateness The pour flush toilet is appropriate for those who sit or squat (pedestal or slab), as well as for those who cleanse with water. Yet, it is only appropriate when there is a constant supply of water available. The pour flush toilet requires (much) less water than a traditional Cistern Flush Toilet. However, because a smaller amount of water is used, the pour flush toilet may clog more easily and, thus, require more maintenance.
If water is available, this type of toilet is appropriate for both public and private applications.

Health Aspects/Acceptance The pour flush toilet (or squatting pan) prevents users from seeing or smelling the excreta of previous users. Thus, it is generally well accepted. Provided that the water seal is working well, there should be almost no odours and the toilet should be clean and comfortable to use.

Operation & Maintenance Because there are no mechanical parts, pour flush toilets are quite robust and rarely require repair. Despite the fact that it is a water-based toilet, it should be cleaned regularly to maintain hygiene and prevent the buildup of stains. To reduce water requirements for flushing and to prevent clogging, it is recommended that dry cleansing materials and products used for menstrual hygiene be collected separately and not flushed down the toilet.

Pros & Cons

+ The water seal effectively prevents odours
+ The excreta of one user are flushed away before the next user arrives
+ Suitable for all types of users (sitters, squatters, washers, wipers)
+ Low capital costs; operating costs depend on the price of water
- Requires a constant source of water (can be recycled water and/or collected rainwater)
- Requires materials and skills for production that are not available everywhere
- Coarse dry cleansing materials may clog the water seal

References & Further Reading

_ Mara, D. D. (1985). *The Design of Pour-Flush Latrines.* UNDP Interregional Project INT/81/047, The World Bank and UNDP, Washington, D.C., US.
Available at: documents.worldbank.org/curated/en/home

_ Mara, D. D. (1996). *Low-Cost Urban Sanitation.* Wiley, Chichester, UK.
(Provides detailed drawings of Indian glass-fibre squat pan and trap with dimensions and critical design criteria. A description of how to modify a pour flush toilet to a cistern flush toilet is included.)

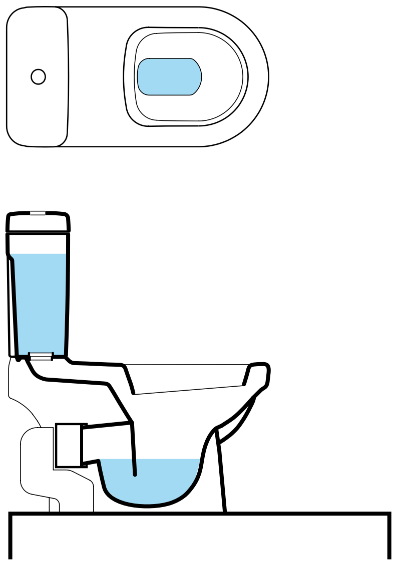
_ Roy, A. K., Chatterjee, P. K., Gupta, K. N., Khare, S. T., Rau, B. B. and Singh, R. S. (1984). *Manual on the Design, Construction and Maintenance of Low-Cost Pour-Flush Waterseal Latrines in India.* UNDP Interregional Project INT/81/047, The World Bank and UNDP, Washington, D.C., US.
Available at: documents.worldbank.org/curated/en/home
(Provides specifications for pour flush toilets and connections)

U.5 Cistern Flush Toilet

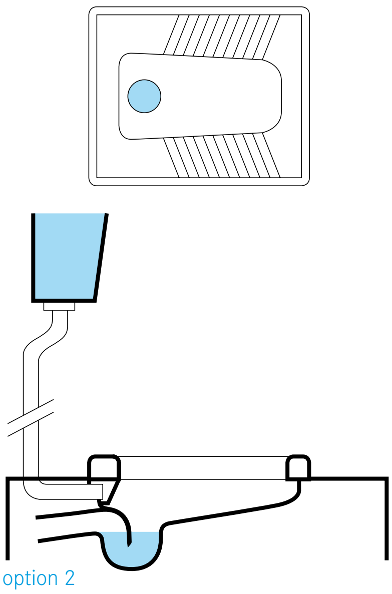
Applicable to:
Systems 6-8

Inputs: Faeces, Urine, Flushwater (Anal Cleansing Water)(Dry Cleansing Materials)

Outputs: Blackwater



option 1



option 2

The cistern flush toilet is usually made of porcelain and is a mass-produced, factory-made User Interface. The flush toilet consists of a water tank that supplies the water for flushing the excreta and a bowl into which the excreta are deposited.

The attractive feature of the cistern flush toilet is that it incorporates a sophisticated water seal to prevent odours from coming back up through the plumbing. Water that is stored in the cistern above the toilet bowl is released by pushing or pulling a lever. This allows the water to run into the bowl, mix with the excreta, and carry them away.

Design Considerations Modern toilets use 6 to 9 L per flush, whereas older models were designed for flushwater quantities of up to 20 L. There are different low-volume flush toilets currently available that can be used with as little as 3 L of water per flush. In some cases, the volume of water used per flush is not sufficient to empty the bowl and, consequently, the user has to flush two or more times to adequately clean the bowl, which negates the intended saving of water.
A good plumber is required to install a flush toilet. The plumber will ensure that all valves are connected and sealed properly, therefore, minimizing leakage.

Appropriateness A cistern flush toilet should not be considered unless all of the connections and hardware accessories are available locally. The cistern flush toilet must be connected to both a constant source of water for flushing and a Collection and Storage/Treatment or Conveyance technology to receive the blackwater.
The cistern flush toilet is suitable for both public and private applications.

Health Aspects/Acceptance It is a safe and comfortable toilet to use provided it is kept clean.

Operation & Maintenance Although flushwater continuously rinses the bowl, the toilet should be scrubbed clean regularly to maintain hygiene and prevent the buildup of stains. Maintenance is required for the replacement or repair of some mechanical parts or fittings. Menstrual hygiene products should be collected in a separate bin.

Pros & Cons

+ The excreta of one user are flushed away before the next user arrives
+ No real problems with odours if used correctly
+ Suitable for all types of users (sitters, squatters, wipers and washers)
- High capital costs; operating costs depend on the price of water
- Requires a constant source of water
- Cannot be built and/or repaired locally with available materials

References & Further Reading

_ Maki, B. (2005). *Assembling and Installing a New Toilet.* Hammerzone.com.
Available at: www.hammerzone.com
(Describes how to install a toilet with full colour photos and step-by-step instructions)

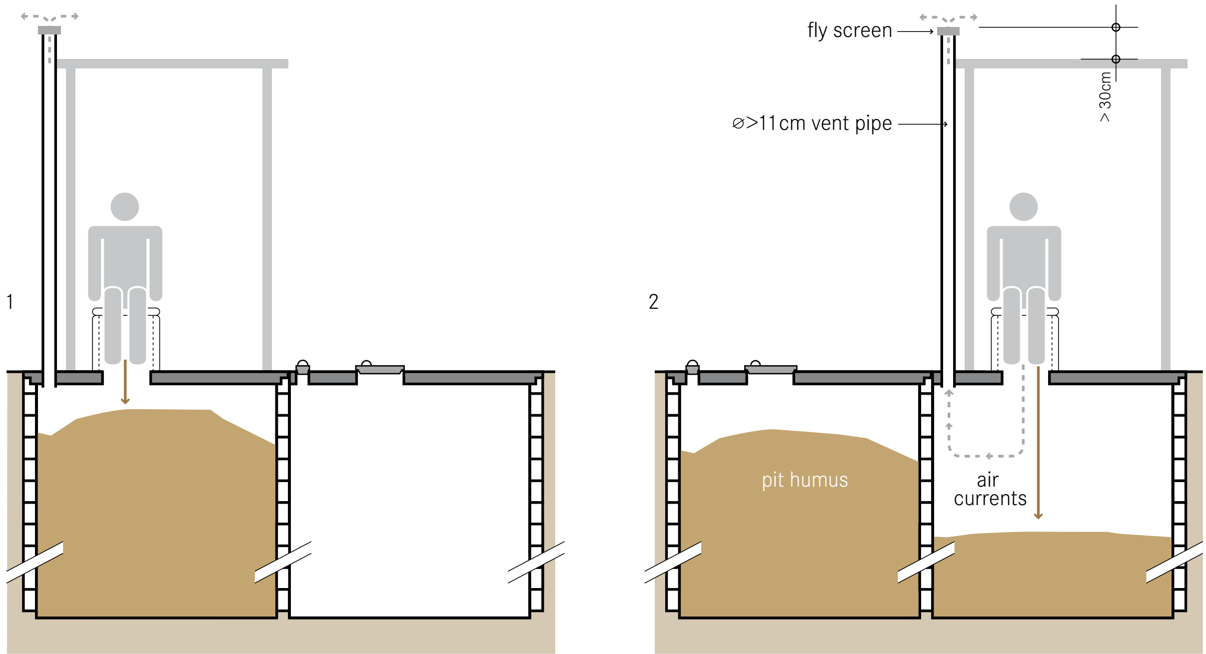
_ Vandervort, D. (2007). *Toilets: Installation and Repair.* HomeTips.com.
Available at: www.hometips.com/bathroom_toilets.html
(Describes each part of the toilet in detail and provides links to other tools, such as how to install a toilet, how to fix a leaking toilet and other toilet essentials)

S.4

Double Ventilated Improved Pit (VIP)

Applicable to:
System 2

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



The double VIP has almost the same design as the Single VIP (S.3) with the added advantage of a second pit that allows it to be used continuously and permits safer and easier emptying.

By using two pits, one pit can be used, while the content of the second rests, drains, reduces in volume, and degrades. When the second pit is almost full (the excreta is 50 cm from the top of the pit), it is covered, and the content of the first pit is removed. Due to the extended resting time (at least 1 or 2 years after several years of filling), the material within the pit is partially sanitized and humus-like.

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

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

Health Aspects/Acceptance The double VIP can be a very clean, comfortable and well accepted sanitation option, in some cases even more so than a water-based technology. However, some health concerns exist:

• Leachate can contaminate groundwater;
• Pits are susceptible to failure and/or overflowing during floods;
• Health risks from flies are not completely removed by ventilation.

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

Pros & Cons

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

References & Further Reading

_ ARGOSS (2001). *Guidelines for Assessing the Risk to Groundwater from on-Site Sanitation.* British Geological Survey Commissioned Report, CR/01/142, Keyworth, UK.
Available at: www.bgs.ac.uk

_ Franceys, R., Pickford, J. and Reed, R. (1992). *A Guide to the Development of on-Site Sanitation.* WHO, Geneva, CH.
Available at: www.susana.org/library

_ Graham, J. P. and Polizzotto, M. L. (2013). *Pit Latrines and Their Impacts on Groundwater Quality: A Systematic Review.* Environmental Health Perspectives, National Institute of Environmental Health Sciences, Research Triangle Park, US.
Available at: www.ehponline.org

_ Mara, D. D. (1984). *The Design of Ventilated Improved Pit Latrines.* UNDP Interregional Project INT/81/047, The World Bank and UNDP, Washington, D.C., US.
Available at: documents.worldbank.org/curated/en/home
(A good reference for detailed double VIP design information)

_ Mara, D. D. (1996). *Low-Cost Urban Sanitation.* Wiley, Chichester, UK.
(General description of VIPs with a focus on the ventilation system)

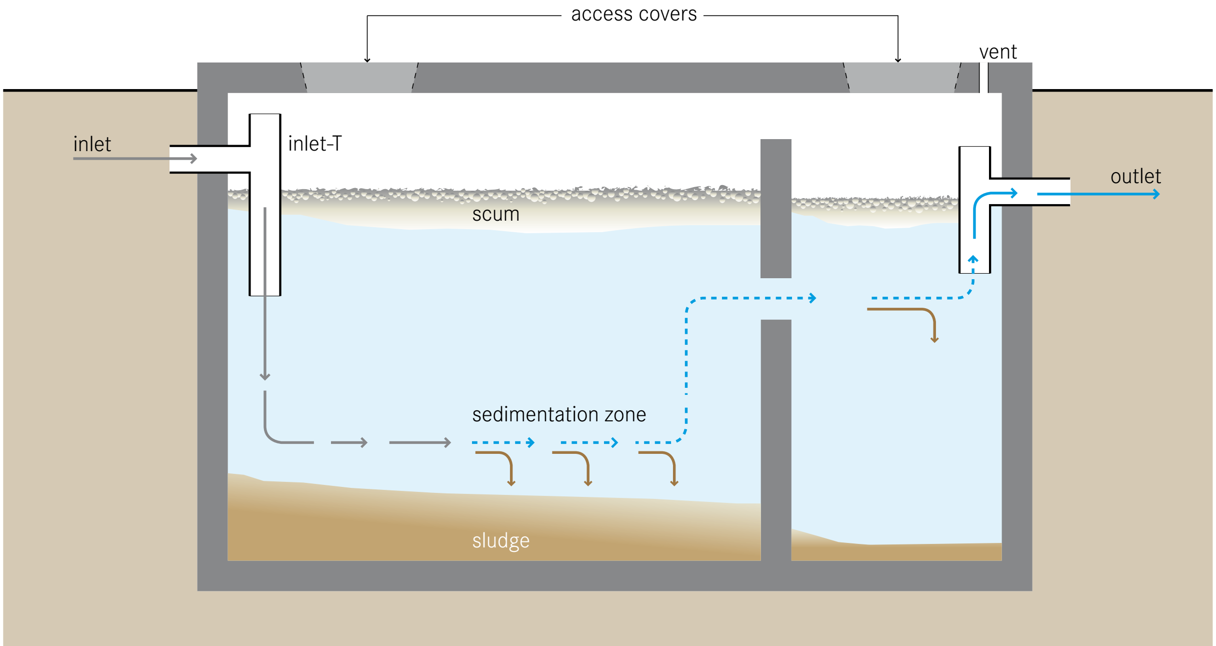
_ Morgan, P. R. (2009). *Ecological Toilets. Start Simple and Upgrade from Arborloo to VIP.* Stockholm Environment Institute, Stockholm, SE.
Available at: www.ecosanres.org

S.9

Septic Tank

Applicable to:
Systems 6, 7

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



A septic tank is a watertight chamber made of concrete, fibreglass, PVC or plastic, through which blackwater and greywater flows for primary treatment. Settling and anaerobic processes reduce solids and organics, but the treatment is only moderate.

Liquid flows through the tank and heavy particles sink to the bottom, while scum (mostly oil and grease) floats to the top. Over time, the solids that settle to the bottom are degraded anaerobically. However, the rate of accumulation is faster than the rate of decomposition, and the accumulated sludge and scum must be periodically removed. The effluent of the septic tank must be dispersed by using a Soak Pit (D.7) or Leach Field (D.8), or transported to another treatment technology via a Solids-Free Sewer (C.5).
Generally, the removal of 50% of solids, 30 to 40% of BOD and a 1-log removal of E. coli can be expected in a well-designed and maintained septic tank, although efficiencies vary greatly depending on operation and maintenance and climatic conditions.

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

Appropriateness This technology is most commonly applied at the household level. Larger, multi-chamber septic tanks can be designed for groups of houses and/or public buildings (e.g., schools).

A septic tank is appropriate where there is a way of dispersing or transporting the effluent. If septic tanks are used in densely populated areas, onsite infiltration should not be used, otherwise, the ground will become oversaturated and contaminated, and wastewater may rise up to the surface, posing a serious health risk. Instead, the septic tanks should be connected to some type of Conveyance technology, through which the effluent is transported to a subsequent Treatment or Disposal site. Even though septic tanks are watertight, it is not recommended to construct them in areas with high groundwater tables or where there is frequent flooding.

Because the septic tank must be regularly desludged, a vacuum truck should be able to access the location. Often, septic tanks are installed in the home, under the kitchen or bathroom, which makes emptying difficult.

Septic tanks can be installed in every type of climate, although the efficiency will be lower in colder climates. They are not efficient at removing nutrients and pathogens.

Health Aspects/Acceptance Under normal operating conditions, users do not come in contact with the influent or effluent. Effluent, scum and sludge must be handled with care as they contain high levels of pathogenic organisms.

Users should be careful when opening the tank because noxious and flammable gases may be released.

Operation & Maintenance Because of the delicate ecology, care should be taken not to discharge harsh chemicals into the septic tank. Scum and sludge levels need to be monitored to ensure that the tank is functioning well. Generally, septic tanks should be emptied every 2 to 5 years. This is best done by using a Motorized Emptying and Transport technology (C.3), but Human-Powered Emptying (C.2) can also be an option.

Septic tanks should be checked from time to time to ensure that they are watertight.

Pros & Cons

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

References & Further Reading

_ Crites, R. and Tchobanoglous, G. (1998). *Small and Decentralized Wastewater Management Systems.* WCB/McGraw-Hill, New York, US.

_ Mara, D. D. (1996). *Low-Cost Urban Sanitation.* Wiley, Chichester, UK.
(Sizing, volume and emptying calculations and example design solutions – Chapter 6)

_ Oxfam (2008). *Septic Tank Guidelines.* Technical Brief. Oxfam GB, Oxford, UK.
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_ Polprasert, C. and Rajput, V. S. (1982). *Environmental Sanitation Reviews. Septic Tank and Septic Systems.* Environmental Sanitation Information Center, AIT, Bangkok, TH. pp. 68-74.
(Comprehensive design manual)

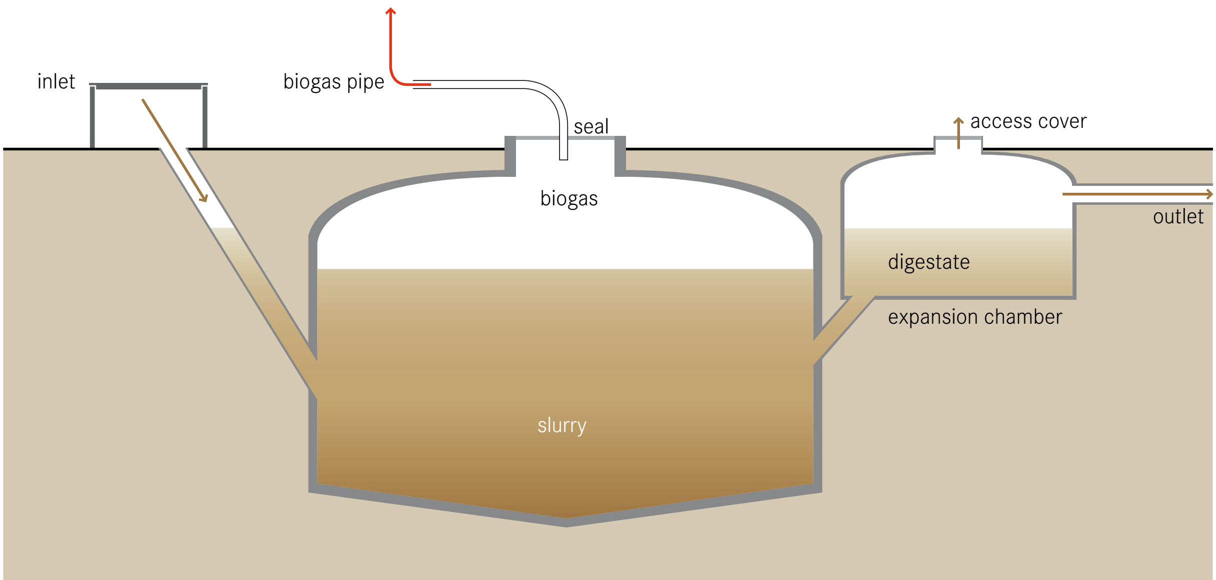
_ Ulrich, A. (Ed.), Reuter, S. (Ed.), Gutterer, B. (Ed.), Sasse, L., Panzerbieter, T. and Reckerzügel, T. (2009). *Decentralised Wastewater Treatment Systems (DEWATS) and Sanitation in Developing Countries. A Practical Guide.* WEDC, Loughborough University, Leicestershire, UK.

S.12

Biogas Reactor

Applicable to:
System 5

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



A biogas reactor or anaerobic digester is an anaerobic treatment technology that produces (a) a digested slurry (digestate) that can be used as a fertilizer and (b) biogas that can be used for energy. Biogas is a mix of methane, carbon dioxide and other trace gases which can be converted to heat, electricity or light.

A biogas reactor is an airtight chamber that facilitates the anaerobic degradation of blackwater, sludge, and/or biodegradable waste. It also facilitates the collection of the biogas produced in the fermentation processes in the reactor. The gas forms in the slurry and collects at the top of the chamber, mixing the slurry as it rises. The digestate is rich in organics and nutrients, almost odourless and pathogens are partly inactivated.

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

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

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

Appropriateness This technology can be applied at the household level, in small neighbourhoods or for the stabilization of sludge at large wastewater treatment plants. It is best used where regular feeding is possible. Often, a biogas reactor is used as an alternative to a Septic Tank (S.9), since it offers a similar level of treatment, but with the added benefit of biogas. However, significant gas production cannot be achieved if blackwater is the only input. The highest levels of biogas production are obtained with concentrated substrates, which are rich in organic material, such as animal manure and organic market or household waste. It can be efficient to co-digest blackwater from a single household with manure if the latter is the main source of feedstock. Greywater should not be added as it substantially reduces the HRT. Wood material and straw are difficult to degrade and should be avoided in the substrate.
Biogas reactors are less appropriate for colder climates as the rate of organic matter conversion into biogas is very low below 15 °C. Consequently, the HRT needs to be longer and the design volume substantially increased.

Health Aspects/Acceptance The digestate is partially sanitized but still carries a risk of infection. Depending on its end-use, further treatment might be required. There are also dangers associated with the flammable gases that, if mismanaged, could be harmful to human health.

Operation & Maintenance If the reactor is properly designed and built, repairs should be minimal. To start the reactor, it should be inoculated with anaerobic bacteria, e.g., by adding cow dung or Septic Tank sludge. Organic waste used as substrate should be shredded and mixed with water or digestate prior to feeding.
Gas equipment should be carefully and regularly cleaned so that corrosion and leaks are prevented. Grit and sand that have settled to the bottom should be removed. Depending on the design and the inputs, the reactor should be emptied once every 5 to 10 years.

Pros & Cons
+ Generation of renewable energy
+ Small land area required (most of the structure can be built underground)
+ No electrical energy required
+ Conservation of nutrients
+ Long service life
+ Low operating costs
- Requires expert design and skilled construction
- Incomplete pathogen removal, the digestate might require further treatment
- Limited gas production below 15 °C

References & Further Reading

- CMS (1996). *Biogas Technology: A Training Manual for Extension.* FAO/TCP/NEP/4451-T. Consolidated Management Services, Kathmandu, NP.
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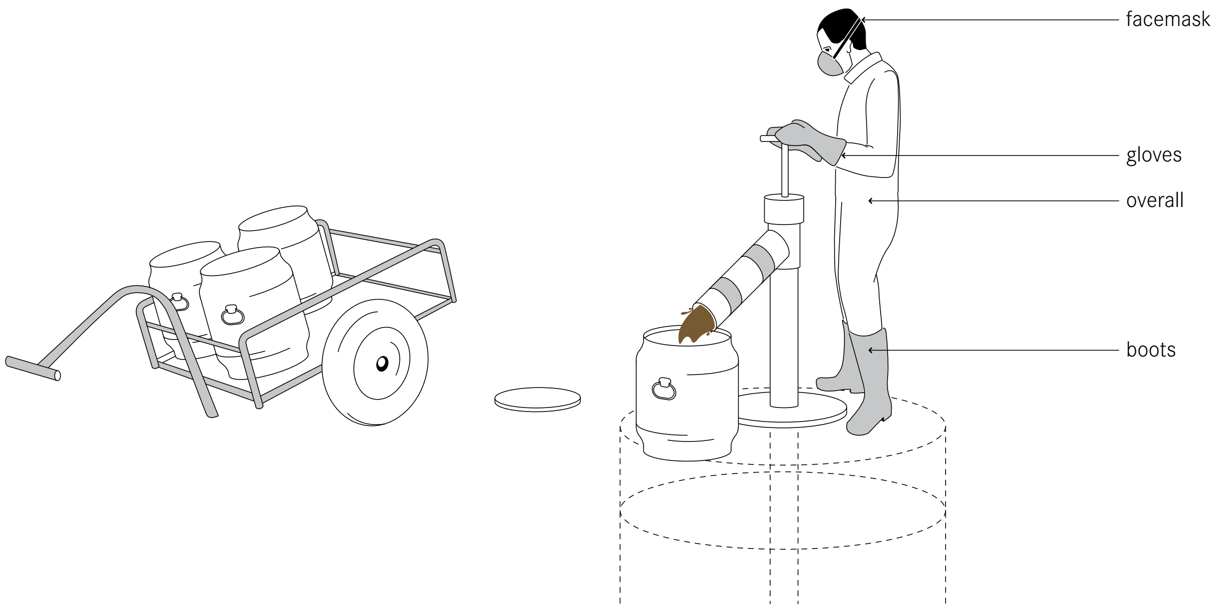
  Available at: www.sandec.ch

C.2 Human-Powered Emptying and Transport

Applicable to:
Systems 1-4, 6, 7

Application Level:	**Management Level:**	**Inputs/Outputs:**
★★ Household	★★ Household	Sludge, Dried Faeces
★★ Neighbourhood	★★ Shared	Compost, Pit Humus
City	★★ Public	



Human-powered emptying and transport refers to the different ways by which people can manually empty and/or transport sludge and solid products generated in onsite sanitation facilities.

Human-powered emptying of pits, vaults and tanks can be done in one of two ways:

1) using buckets and shovels, or
2) using a portable, manually operated pump specially designed for sludge (e.g., the Gulper, the Rammer, the MDHP or the MAPET).

Some sanitation technologies can only be emptied manually, for example, the Fossa Alterna (S.5) or Dehydration Vaults (S.7). These technologies must be emptied with a shovel because the material is solid and cannot be removed with a vacuum or a pump.

When sludge is viscous or watery it should be emptied with a hand pump or a vacuum truck, and not with buckets because of the high risk of collapsing pits, toxic fumes, and exposure to unsanitized sludge.

Manual sludge pumps are relatively new inventions and have shown promise as being low-cost, effective solutions for sludge emptying where, because of access, safety or economics, other emptying techniques are not possible.

Design Considerations Sludge hand pumps, such as the Gulper, work on the same concept as water hand pumps: the bottom of the pipe is lowered into the pit/tank while the operator remains at the surface. As the operator pushes and pulls the handle, the sludge is pumped up and is then discharged through the discharge spout. The sludge can be collected in barrels, bags or carts, and removed from the site with little danger to the operator. Hand pumps can be locally made with steel rods and valves in a PVC casing.

A MAPET (MAnual Pit Emptying Technology) consists of a manually operated pump connected to a vacuum tank mounted on a pushcart. A hose is connected to the tank and is used to suck sludge from the pit. When the wheel of the hand pump is turned, air is sucked out of the vacuum tank and sludge is sucked up into the tank. Depending on the consistency of the sludge, the MAPET can pump up to a height of 3 m.

Appropriateness Hand pumps can be used for liquid and, to a certain degree, viscous sludge. Domestic refuse in the pit makes emptying much more difficult. The pumping of sludge, which contains coarse solid wastes or grease, can lead to clogging of the device, and chemical additives can corrode pipes, pumps and tanks. The hand pump is a significant improvement over the bucket method and could prove to be a sustainable business opportunity in some regions. Manually operated sludge pumps are appropriate for areas that are not served or not accessible by vacuum trucks, or where vacuum truck emptying is too costly. They are well suited to dense, urban and informal settlements, although the type and size of transport vehicle determines the feasible distance to the discharge point. Large vehicles may not be able to manoeuvre within narrow streets and alleys, while smaller vehicles may not be able to travel long distances. These technologies are more feasible when there is a Transfer Station (C.7) nearby.

Health Aspects/Acceptance Depending on cultural factors and political support, workers dealing with manual emptying may be viewed as providing an important service to the community. Government-run programmes should strive to legitimize the work of the labourers and create an enabling environment by providing permits and licences, as well as helping to legalize the practice of emptying latrines manually.
The most important aspect of manual emptying is ensuring that workers are adequately protected with gloves, boots, overalls and facemasks. Regular medical exams and vaccinations should be required for everyone working with sludge.

Operation & Maintenance It is a common practice to add chemicals or oil during the pit emptying process to avoid odours. This is not recommended, however, because it causes difficulties in the subsequent treatment units, as well as additional health threats to the workers.
If manual access to the contents of a pit requires demolishing the slab, it may be more cost-effective to use a manual sludge pump to empty the latrine. However, hand pumps cannot empty the entire pit and, therefore, emptying may be required more frequently (once a year).
Manually operated sludge pumps require daily maintenance (cleaning, repairing and disinfection). Workers who manually empty latrines should clean and maintain their protective clothing and tools to prevent contact with the sludge.

Pros & Cons

+ Potential for local job creation and income generation
+ Simple hand pumps can be built and repaired with locally available materials
+ Low capital costs; variable operating costs depending on transport distance
+ Provides services to areas/communities without sewers
- Spills can happen which could pose potential health risks and generate offensive smells
- Time consuming: emptying pits out can take several hours/days depending on their size
- Garbage in pits may block pipe
- Some devices may require specialized repair (welding)

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Available at: www.bpdws.org
(A comparison of two manual emptying projects)

_ Ideas at Work (2007). *The 'Gulper' – a Manual Latrine/Drain Pit Pump.* Ideas at Work, Phnom Penh, KH.
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(Case study about a test of the Gulper by informal service providers)

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_ Oxfam (2008). *Manual Desludging Hand Pump (MDHP) Resources.* Oxfam GB, Oxford, UK.
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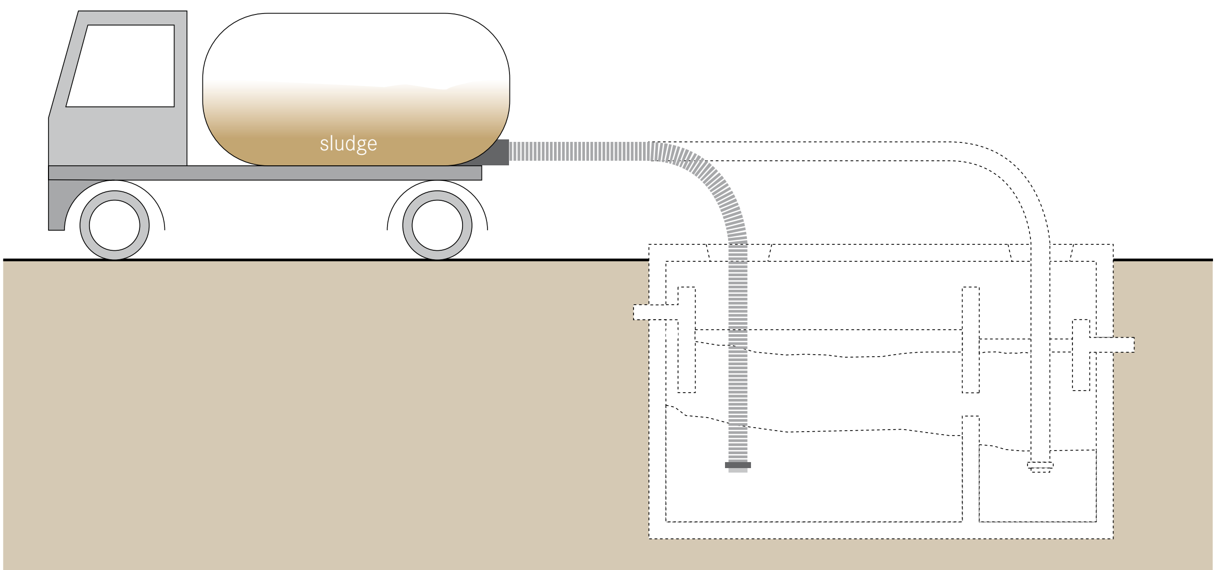
C.3

Motorized Emptying and Transport

Applicable to:
Systems 1, 4-7, 9

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



Motorized emptying and transport refers to a vehicle equipped with a motorized pump and a storage tank for emptying and transporting faecal sludge and urine. Humans are required to operate the pump and manoeuvre the hose, but sludge is not manually lifted or transported.

A truck is fitted with a pump which is connected to a hose that is lowered down into a tank (e.g., Septic Tank, S.9) or pit, and the sludge is pumped up into the holding tank on the vehicle. This type of design is often referred to as a vacuum truck.
Alternative motorized vehicles or machines have been developed for densely populated areas with limited access. Designs such as the Vacutug, Dung Beetle, Molsta or Kedoteng carry a small sludge tank and a pump and can negotiate narrow pathways.

Design Considerations Generally, the storage capacity of a vacuum truck is between 3 and 12 m^3. Local trucks are commonly adapted for sludge transport by equipping them with holding tanks and pumps. Modified pick-ups and tractor trailers can transport around 1.5 m^3, but capacities vary. Smaller vehicles for densely populated areas have capacities of 500 to 800 L. These vehicles use, for example, two-wheel tractor or motorcycle based drives and can reach speeds of up to 12 km/h.
Pumps can usually only suck down to a depth of 2 to 3 m (depending on the strength of the pump) and must be located within 30 m of the pit. In general, the closer the vacuum pump can be to the pit, the easier it is to empty.

Appropriateness Depending on the Collection and Storage technology, the sludge can be so dense that it cannot be easily pumped. In these situations it is necessary to thin the solids with water so that they flow more easily, but this may be inefficient and costly. Garbage and sand make emptying much more difficult and clog the pipe or pump. Multiple truckloads may be required for large Septic Tanks.
Although large vacuum trucks cannot access areas with narrow or non-driveable roads, they remain the norm for municipalities and sanitation authorities. These trucks can rarely make trips to remote areas (e.g., in the periphery of a city) since the income generated may not offset the cost of fuel and time. Therefore, the treatment site must be within reach from the serviced areas. Transfer Stations (C.7) and adequate treatment are also

crucial for service providers using small-scale motorized equipment. Field experiences have shown that the existing designs for dense urban areas are limited in terms of their emptying effectiveness and travel speed, and their ability to negotiate slopes, poor roads and very narrow lanes. Moreover, demand and market constraints have prevented them from becoming commercially viable. Under favourable circumstances, small vehicles like the Vacutug are able to recover the operating and maintenance costs. However, the capital costs are still too high to sustainably run a profitable business.

Both the sanitation authority and private entrepreneurs may operate vacuum trucks, although the price and level of service may vary significantly. Private operators may charge less than public ones, but may only afford to do so if they do not discharge the sludge at a certified facility. Private and municipal service providers should work together to cover the whole faecal sludge management chain.

Health Aspects/Acceptance The use of a vacuum truck presents a significant health improvement over manual emptying and helps to maintain the Collection and Storage technology. Still, truck operators are not always accepted by the community and may face difficulties with finding appropriate locations to dump the collected sludge.

Operation & Maintenance Most pump trucks are manufactured in North America, Asia or Europe. Thus, in some regions it is difficult to locate spare parts and a mechanic to repair broken pumps or trucks. New trucks are very expensive and sometimes difficult to obtain. Therefore, older trucks are often used, but the savings are offset by the resulting high maintenance and fuel costs that can account for more than two thirds of the total costs incurred by a truck operator. Truck owners must be conscientious to save money for the purchase of expensive replacement parts, tires and equipment. The lack of preventive maintenance is often the cause for major repairs.

The addition of chemical additives for desludging is not recommended because they tend to corrode the sludge tank.

Pros & Cons

+ Fast, hygienic and generally effective sludge removal
+ Efficient transport possible with large vacuum trucks
+ Potential for local job creation and income generation
+ Provides an essential service to unsewered areas
- Cannot pump thick, dried sludge (must be thinned with water or manually removed)
- Garbage in pits may block hose
- Cannot completely empty deep pits due to limited suction lift
- Very high capital costs; variable operating costs depending on use and maintenance
- Hiring a vacuum truck may be unaffordable for poor households
- Not all parts and materials may be locally available
- May have difficulties with access

References & Further Reading

- Boesch, A. and Schertenleib, R. (1985). *Pit Emptying on-Site Excreta Disposal Systems. Field Tests with Mechanized Equipment in Gaborone (Botswana).* International Reference Centre for Waste Disposal, Dübendorf, CH.
  Available at: www.sandec.ch
  (Comprehensive summary of technical components, performance with different sludge types, and maintenance)

- Chowdhry, S. and Koné, D. (2012). *Business Analysis of Fecal Sludge Management: Emptying and Transportation Services in Africa and Asia.* Bill & Melinda Gates Foundation, Seattle, US.
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- O'Riordan, M. (2009). *Investigation into Methods of Pit Latrine Emptying. Management of Sludge Accumulation in VIP Latrines.* WRC Project 1745, Water Research Commission, Pretoria, ZA.
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  (Includes a detailed analysis of field experiences with the Vacutug)

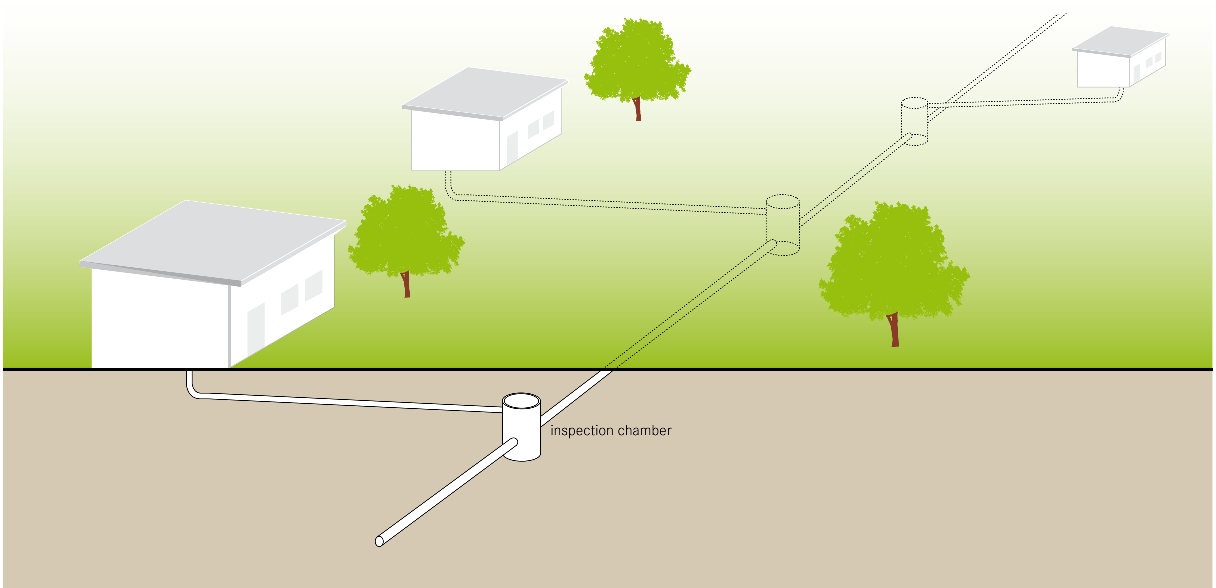
- Strande, L., Ronteltap, M. and Brdjanovic, D. (Eds.) (2014). *Faecal Sludge Management. Systems Approach for Implementation and Operation.* IWA Publishing, London, UK.
  Available at: www.sandec.ch
  (Detailed book compiling the current state of knowledge on all aspects related to FSM)

C.4

Simplified Sewer

Applicable to:
Systems 7-9

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



A simplified sewer describes a sewerage network that is constructed using smaller diameter pipes laid at a shallower depth and at a flatter gradient than Conventional Sewers (C.6). The simplified sewer allows for a more flexible design at lower costs.

Conceptually, simplified sewerage is the same as Conventional Gravity Sewerage, but without unnecessarily conservative design standards and with design features that are better adapted to the local situation. The pipes are usually laid within the property boundaries, through either the back or front yards, rather than beneath the central road, allowing for fewer and shorter pipes. Because simplified sewers are typically installed within the condominium, they are often referred to as condominial sewers. The pipes can also be routed in access ways, which are too narrow for heavy traffic, or underneath pavements (sidewalks). Since simplified sewers are installed where they are not subjected to heavy traffic loads, they can be laid at a shallow depth and little excavation is required.

Design Considerations In contrast to Conventional Sewers that are designed to ensure a minimum self-cleansing velocity, the design of simplified sewers is based on a minimum tractive tension of 1 N/m^2 (1 Pa) at peak flow. The minimum peak flow should be 1.5 L/s and a minimum sewer diameter of 100 mm is required. A gradient of 0.5% is usually sufficient. For example, a 100 mm sewer laid at a gradient of 1 m in 200 m will serve around 2,800 users with a wastewater flow of 60 L/person/day.
PVC pipes are recommended to use. The depth at which they should be laid depends mainly on the amount of traffic. Below sidewalks, covers of 40 to 65 cm are typical. The simplified design can also be applied to sewer mains; they can also be laid at a shallow depth, provided that they are placed away from traffic.
Expensive manholes are normally not needed. At each junction or change in direction, simple inspection chambers (or cleanouts) are sufficient. Inspection boxes are also used at each house connection. Where kitchen greywater contains an appreciable amount of oil and grease, the installation of grease traps (see PRE, p. 100) is recommended to prevent clogging.
Greywater should be discharged into the sewer to ensure adequate hydraulic loading, but stormwater connections should be discouraged. However, in practice

it is difficult to exclude all stormwater flows, especially where there is no alternative for storm drainage. The design of the sewers (and treatment plant) should, therefore, take into account the extra flow that may result from stormwater inflow.

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

Health Aspects/Acceptance If well constructed and maintained, sewers are a safe and hygienic means of transporting wastewater. Users must be well trained regarding the health risks associated with removing blockages and maintaining inspection chambers.

Operation & Maintenance Trained and responsible users are essential to ensure that the flow is undisturbed and to avoid clogging by trash and other solids. Occasional flushing of the pipes is recommended to insure against blockages. Blockages can usually be removed by opening the cleanouts and forcing a rigid wire through the pipe. Inspection chambers must be periodically emptied to prevent grit overflowing into the system. The operation of the system depends on clearly defined responsibilities between the sewerage authority and the community. Ideally, households will be responsible for the maintenance of pre-treatment units and the condominial part of the sewer. However, in practice this may not be feasible because users may not detect problems before they become severe and costly to repair. Alternatively, a private contractor or users committee can be hired to do the maintenance.

Pros & Cons

+ Can be laid at a shallower depth and flatter gradient than Conventional Sewers
+ Lower capital costs than Conventional Sewers; low operating costs
+ Can be extended as a community grows
+ Greywater can be managed concurrently
+ Does not require onsite primary treatment units
- Requires repairs and removals of blockages more frequently than a Conventional Gravity Sewer
- Requires expert design and construction
- Leakages pose a risk of wastewater exfiltration and groundwater infiltration and are difficult to identify

References & Further Reading

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(Design guidelines for manual calculations)

_ Mara, D. D. (1996a). *Low-Cost Sewerage.* Wiley, Chichester, UK.
(Assessment of different low-cost systems and case studies)

_ Mara, D. D. (1996b). *Low-Cost Urban Sanitation.* Wiley, Chichester, UK. pp. 109-139.
(Comprehensive summary including design examples)

_ Mara, D. D. (2005). *Sanitation for All in Periurban Areas? Only If We Use Simplified Sewerage.* Water Science & Technology: Water Supply 5 (6): 57-65.
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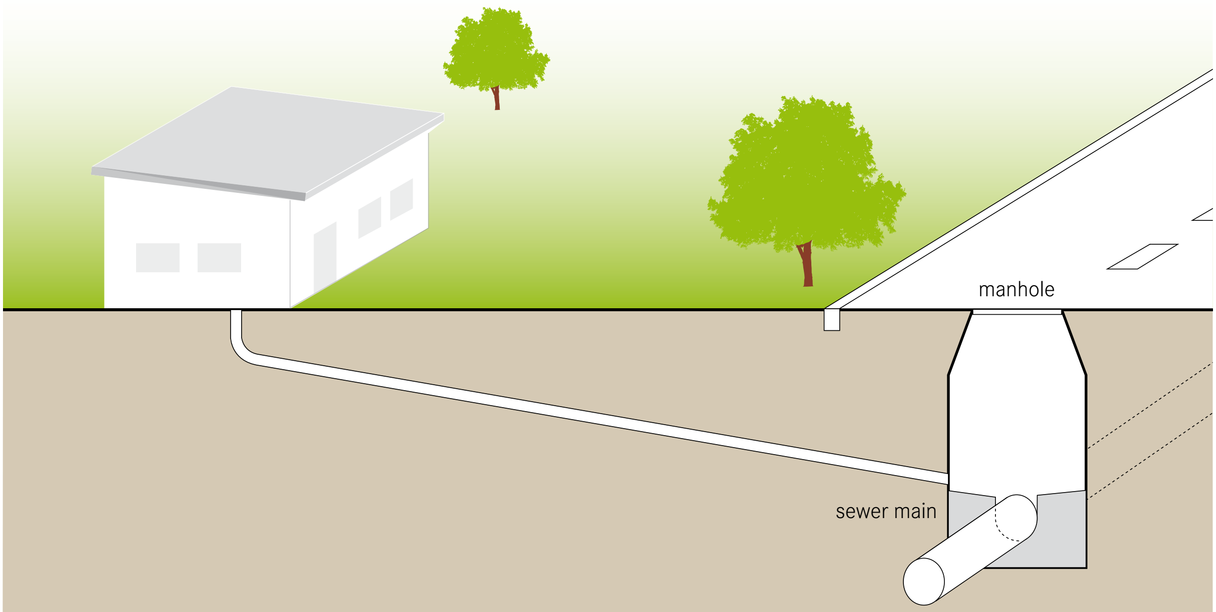
(Comprehensive coverage of theory and design including a program to be used as a design aid)

_ Watson, G. (1995). *Good Sewers Cheap? Agency-Customer Interactions in Low-Cost Urban Sanitation in Brazil.* Water and Sanitation Division, The World Bank, Washington, D.C., US. Available at: www.wsp.org
(A summary of large-scale projects in Brazil)

C.6 Conventional Gravity Sewer

Applicable to:
Systems 8, 9

Application Level:	**Management Level:**	**Inputs/Outputs:**
Household	Household	Blackwater, Brownwater
★ Neighbourhood	Shared	Greywater, (Stormwater)
★★ City	★★ Public	



Conventional gravity sewers are large networks of underground pipes that convey blackwater, greywater and, in many cases, stormwater from individual households to a (Semi-) Centralized Treatment facility, using gravity (and pumps when necessary).

The conventional gravity sewer system is designed with many branches. Typically, the network is subdivided into primary (main sewer lines along main roads), secondary and tertiary networks (networks at the neighbourhood and household level).

Design Considerations Conventional gravity sewers normally do not require onsite pre-treatment, primary treatment or storage of the household wastewater before it is discharged. The sewer must be designed, however, so that it maintains self-cleansing velocity (i.e., a flow that will not allow particles to accumulate). For typical sewer diameters, a minimum velocity of 0.6 to 0.7 m/s during peak dry weather conditions should be adopted. A constant downhill gradient must be guaranteed along the length of the sewer to maintain self-cleansing flows, which can require deep excavations. When a downhill grade cannot be maintained, a pumping station must be installed. Primary sewers are laid beneath roads, at depths of 1.5 to 3 m to avoid damages caused by traffic loads. The depth also depends on the groundwater table, the lowest point to be served (e.g., a basement) and the topography. The selection of the pipe diameter depends on the projected average and peak flows. Commonly used materials are concrete, PVC, and ductile or cast iron pipes.
Access manholes are placed at set intervals above the sewer, at pipe intersections and at changes in pipeline direction (vertically and horizontally). Manholes should be designed such that they do not become a source of stormwater inflow or groundwater infiltration.
In the case that connected users discharge highly polluted wastewater (e.g., industry or restaurants), onsite pre- and primary treatment may be required before discharge into the sewer system to reduce the risk of clogging and the load of the wastewater treatment plant.
When the sewer also carries stormwater (known as a combined sewer), sewer overflows are required to avoid hydraulic surcharge of treatment plants during rain events. However, combined sewers should no longer be considered state of the art. Rather, local retention and infiltration of stormwater or a separate drainage system

for rainwater are recommended. The wastewater treatment system then requires smaller dimensions and is, therefore, cheaper to build, and there is a higher treatment efficiency for less diluted wastewater.

Appropriateness Because they can be designed to carry large volumes, conventional gravity sewers are very appropriate to transport wastewater to a (Semi-) Centralized Treatment facility. Planning, construction, operation and maintenance require expert knowledge. Construction of conventional sewer systems in dense, urban areas is complicated because it disrupts urban activities and traffic. Conventional gravity sewers are expensive to build and, because the installation of a sewer line is disruptive and requires extensive coordination between authorities, construction companies and property owners, a professional management system must be in place.
Ground shifting may cause cracks in manhole walls or pipe joints, which may become a source of groundwater infiltration or wastewater exfiltration, and compromise the performance of the sewer.
Conventional gravity sewers can be constructed in cold climates as they are dug deep into the ground and the large and constant water flow resists freezing.

Health Aspects/Acceptance If well constructed and maintained, sewers are a safe and hygienic means of transporting wastewater. This technology provides a high level of hygiene and comfort for the user. However, because the waste is conveyed to an offsite location for treatment, the ultimate health and environmental impacts are determined by the treatment provided by the downstream facility.

Operation & Maintenance Manholes are used for routine inspection and sewer cleaning. Debris (e.g., grit, sticks or rags) may accumulate in the manholes and block the lines. To avoid clogging caused by grease, it is important to inform the users about proper oil and grease disposal. Common cleaning methods for conventional gravity sewers include rodding, flushing, jetting and bailing. Sewers can be dangerous because of toxic gases and should be maintained only by professionals, although, in well-organised communities, the maintenance of tertiary networks might be handed over to a well-trained group of community members. Proper protection should always be used when entering a sewer.

Pros & Cons
+ Less maintenance compared to Simplified and Solids-Free Sewers
+ Greywater and possibly stormwater can be managed concurrently
+ Can handle grit and other solids, as well as large volumes of flow
- Very high capital costs; high operation and maintenance costs
- A minimum velocity must be maintained to prevent the deposition of solids in the sewer
- Requires deep excavations
- Difficult and costly to extend as a community changes and grows
- Requires expert design, construction and maintenance
- Leakages pose a risk of wastewater exfiltration and groundwater infiltration and are difficult to identify

References & Further Reading

_ Bizier, P. (Ed.) (2007). *Gravity Sanitary Sewer Design and Construction. Second Edition.* ASCE Manuals and Reports on Engineering Practice No. 60, WEF MOP No. FD-5. American Society of Civil Engineers, New York, US.
(A standard design text used in North America, although local codes and standards should be assessed before choosing a design manual)

_ Tchobanoglous, G. (1981). *Wastewater Engineering: Collection and Pumping of Wastewater.* McGraw-Hill, New York, US.

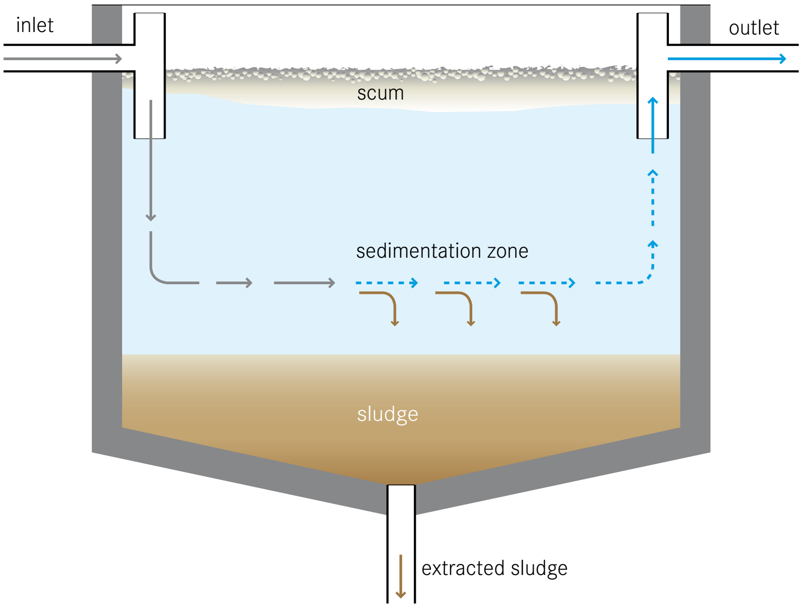
_ U.S. EPA (2002). *Collection Systems Technology Fact Sheet. Sewers, Conventional Gravity.* 832-F-02-007. U.S. Environmental Protection Agency, Washington, D.C., US.
Available at: www.epa.gov
(Good description of the technology, including more detailed design criteria and information on operation and maintenance)

T.1

Settler

Applicable to:
Systems 1, 6-9

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



A settler is a primary treatment technology for wastewater; it is designed to remove suspended solids by sedimentation. It may also be referred to as a sedimentation or settling basin/tank, or clarifier. The low flow velocity in a settler allows settleable particles to sink to the bottom, while constituents lighter than water float to the surface.

Sedimentation is also used for the removal of grit (see PRE, p. 100), for secondary clarification in Activated Sludge treatment (see T.12), after chemical coagulation/precipitation, or for sludge thickening. This technology information sheet discusses the use of settlers as primary clarifiers, which are typically installed after a pre-treatment technology.

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

Settlers may take a variety of forms, sometimes fulfilling additional functions. They can be independent tanks or integrated into combined treatment units. Several other technologies in this Compendium have a primary sedimentation function or include a compartment for primary settling:

- the Septic Tank (S.9), where the low sludge removal frequency leads to anaerobic degradation of the sludge.
- the Anaerobic Baffled Reactor (S.10/T.3) and the Anaerobic Filter (S.11/T.4) both usually include a settler as the first compartment. However, the settler may also be built separately, e.g., in municipal treatment plants or in the case of prefabricated, modular units.
- the Biogas Reactor (S.12/T.17), which can be considered as a settler designed for anaerobic digestion and biogas production.
- the Imhoff Tank (T.2) and the Upflow Anaerobic Sludge Blanket Reactor (UASB, T.11), designed for the digestion of the settled sludge, prevent gases or sludge particles in the lower section from entering/returning to the upper section.
- the Waste Stabilization Ponds (WSP, T.5), of which the first anaerobic pond is for settling
- the Sedimentation/Thickening Ponds (T.13), which are designed for the solid-liquid separation of faecal sludge
- the Solids-Free Sewer (C.5), which includes interceptor tanks at the building level.

Design Considerations The main purpose of a settler is to facilitate sedimentation by reducing the velocity and turbulence of the wastewater stream. Settlers are circular or rectangular tanks that are typically designed for a hydraulic retention time of 1.5-2.5 h. Less time is needed if the BOD level should not be too low for the following biological step. The tank should be designed to ensure satisfactory performance at peak flow. In order to prevent eddy currents and short-circuiting, as well as to retain scum inside the basin, a good inlet and outlet construction with an efficient distribution and collection system (baffles, weirs or T-shaped pipes) is important.

Depending on the design, desludging can be done using a hand pump, airlift, vacuum pump, or by gravity using a bottom outlet. Large primary clarifiers are often equipped with mechanical collectors that continually scrape the settled solids towards a sludge hopper in the base of the tank, from where it is pumped to sludge treatment facilities. A sufficiently sloped tank bottom facilitates sludge removal. Scum removal can also be done either manually or by a collection mechanism.

The efficiency of the primary settler depends on factors like wastewater characteristics, retention time and sludge withdrawal rate. It may be reduced by wind-induced circulation, thermal convection and density currents due to temperature differentials, and, in hot climates, thermal stratification. These phenomena can lead to short-circuiting.
Several possibilities exist to enhance the performance of settlers. Examples include the installation of inclined plates (lamellae) and tubes, which increase the settling area, or the use of chemical coagulants.

Appropriateness The choice of a technology to settle the solids is governed by the size and type of the installation, the wastewater strength, the management capacities and the desirability of an anaerobic process, with or without biogas production.
Technologies that already include some type of primary sedimentation (listed above) do not need a separate settler. Many treatment technologies, however, require preliminary removal of solids in order to function properly. Although the installation of a primary sedimentation tank is often omitted in small activated sludge plants, it is of particular importance for technologies that use a filter material. Settlers can also be installed as stormwater retention tanks to remove a portion of the organic solids that otherwise would be directly discharged into the environment.

Health Aspects/Acceptance To prevent the release of odorous gases, frequent sludge removal is necessary. Sludge and scum must be handled with care as they contain high levels of pathogenic organisms; they require further treatment and adequate disposal. Appropriate protective clothing is necessary for workers who may come in contact with the effluent, scum or sludge.

Operation & Maintenance In settlers that are not designed for anaerobic processes, regular sludge removal is necessary to prevent septic conditions and the build-up and release of gas which can hamper the sedimentation process by re-suspending part of the settled solids. Sludge transported to the surface by gas bubbles is difficult to remove and may pass to the next treatment stage.
Frequent scum removal and adequate treatment/disposal, either with the sludge or separately, is also important.

Pros & Cons
+ Simple and robust technology
+ Efficient removal of suspended solids
+ Relatively low capital and operating costs
- Frequent sludge removal
- Effluent, sludge and scum require further treatment
- Short-circuiting can be a problem

References & Further Reading

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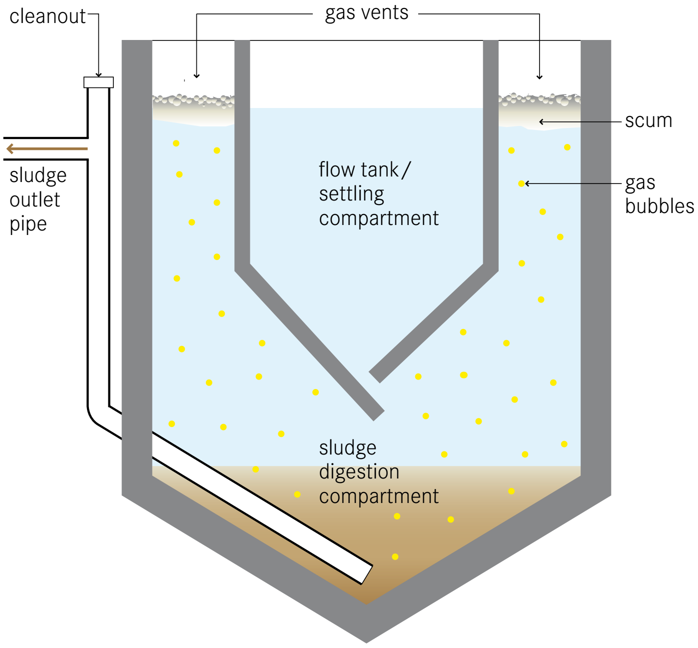
T.2

Imhoff Tank

Applicable to:
Systems 1, 6-9

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



The Imhoff tank is a primary treatment technology for raw wastewater, designed for solid-liquid separation and digestion of the settled sludge. It consists of a V-shaped settling compartment above a tapering sludge digestion chamber with gas vents.

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

Design Considerations The Imhoff tank is usually built underground with reinforced concrete. It can, however, also be built above ground, which makes sludge removal easier due to gravity, although it still requires pumping up of the influent. Small prefabricated Imhoff tanks are also available on the market. Hydraulic retention time is usually not more than 2 to 4 hours to preserve an aerobic effluent for further treatment or discharge. T-shaped pipes or baffles are used at the inlet and the outlet to reduce velocity and prevent scum from leaving the system. The total water depth in the tank from the bottom to the water surface may reach 7 to 9.5 m. The bottom of the settling compartment is typically sloped 1.25 to 1.75 vertical to 1 horizontal and the slot opening can be 150 to 300 mm wide. The walls of the sludge digestion compartment should have an inclination of 45° or more. This allows the sludge to slide down to the centre where it can be removed. Dimensioning of the anaerobic digestion compartment depends mainly on sludge production per population equivalent, on the targeted degree of sludge stabilization (linked to the desludging frequency) and the temperature. The digestion chamber is usually designed for 4 to 12 months sludge storage capacity to allow for sufficient anaerobic digestion. In colder climates longer sludge retention time and, therefore, a greater volume is needed. For desludging, a pipe and pump have to be installed or access provided for vacuum trucks and mobile pumps. A bar screen or grit chamber (see PRE, p. 100) is recommended before the Imhoff tank to prevent coarse material from disturbing the system.

Appropriateness Imhoff tanks are recommended for domestic or mixed wastewater flows between 50 and 20,000 population equivalents. They are able to treat high organic loads and are resistant against organic shock loads. Space requirements are low.
Imhoff tanks can be used in warm and cold climates. As the tank is very high, it can be built underground if the groundwater table is low and the location is not flood prone.

Health Aspects/Acceptance As the effluent is almost odourless, it is a good option for primary treatment if subsequent treatment takes place, e.g., in open ponds, constructed wetlands or trickling filters. Gases produced in low quantities may, however, generate odours locally. Pathogen removal is low and all outputs should be treated. Appropriate protective clothing is necessary for workers who may come in contact with the effluent, scum or sludge.

Operation & Maintenance Operation and maintenance are possible at low cost, if trained personnel are in charge. Flow paths have to be kept open and cleaned out weekly, while scum in the settling compartment and the gas vents has to be removed daily if necessary. Stabilized sludge from the bottom of the digestion compartment should be removed according to the design. A minimum clearance of 50 cm between the sludge blanket and the slot of the settling chamber has to be ensured at all times.

Pros & Cons

+ Solid-liquid separation and sludge stabilization are combined in one single unit
+ Resistant against organic shock loads
+ Small land area required
+ The effluent is not septic (with low odour)
+ Low operating costs

- Very high (or deep) infrastructure; depth may be a problem in case of high groundwater table
- Requires expert design and construction
- Low reduction of pathogens
- Effluent, sludge and scum require further treatment

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- Herrera, A. (2006). *Rehabilitation of the Imhoff Tank Treatment Plant in Las Vegas, Santa Barbara Honduras, Central America.* Master thesis, Department of Civil, Architectural and Environmental Engineering, University of Texas, Austin, US.
  (Case study providing general information about Imhoff tanks and insights into implementation and operational problems. Recommendations for O&M are provided.)

- McLean, R. C. (2009). *Honduras Wastewater Treatment: Chemically Enhanced Primary Treatment and Sustainable Secondary Treatment Technologies for Use with Imhoff Tanks.* Master thesis, Department of Civil and Environmental Engineering, Massachusetts Institute of Technology, Cambridge, US.
  (Case study including a detailed description of the functionality of the Imhoff tank)

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  (Comprehensive handbook about planning and implementation of decentralized wastewater treatment options. It includes case studies and Excel spreadsheets for design calculations.)

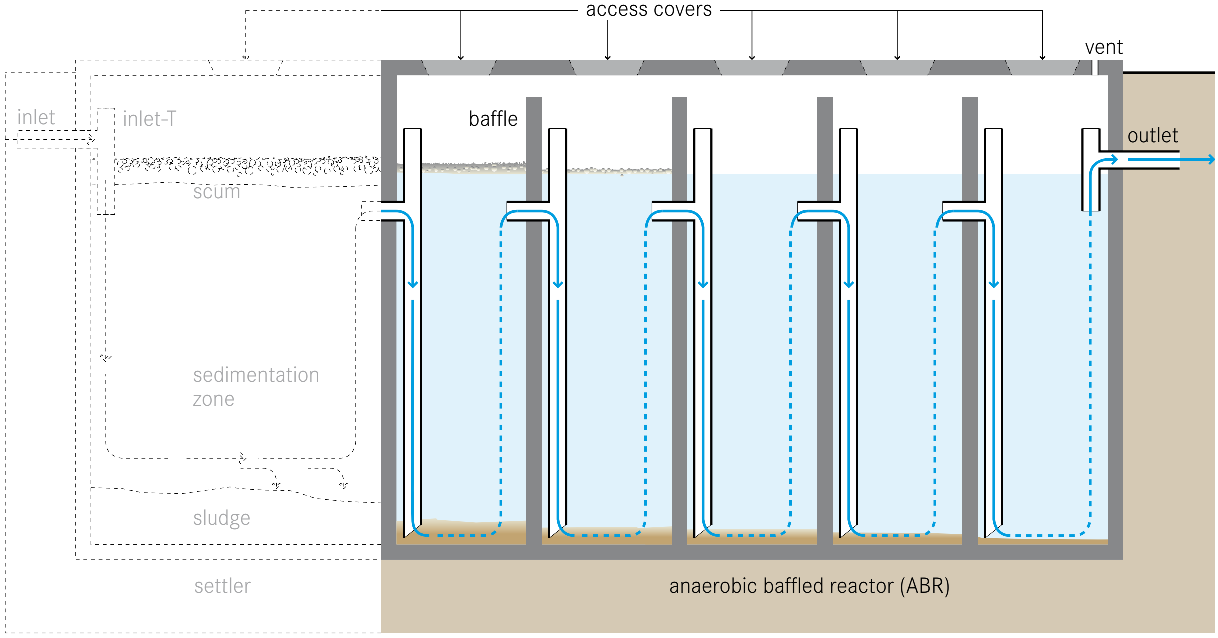
- WSP (Ed.) (2008). *Philippines Sanitation Sourcebook and Decision Aid.* Water and Sanitation Program, Washington, D.C., US.
  Available at: documents.worldbank.org/curated/en/home
  (Basic information about low-cost decentralized sanitation technologies for decision makers. Presents fact sheets about 23 selected options, including the Imhoff tank.)

T.3

Anaerobic Baffled Reactor (ABR)

Applicable to:
Systems 1, 6-9

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



An anaerobic baffled reactor (ABR) is an improved Septic Tank (S.9) with a series of baffles under which the wastewater is forced to flow. The increased contact time with the active biomass (sludge) results in improved treatment.

The upflow chambers provide enhanced removal and digestion of organic matter. BOD may be reduced by up to 90%, which is far superior to its removal in a conventional Septic Tank.

Design Considerations The majority of settleable solids are removed in a sedimentation chamber in front of the actual ABR. Small-scale, stand-alone units typically have an integrated settling compartment (as shown in S.10), but primary sedimentation can also take place in a separate Settler (T.1) or another preceding technology (e.g., existing Septic Tanks). Designs without a settling compartment are of particular interest for (Semi-) Centralized Treatment plants that combine the ABR with another technology for primary settling, or where prefabricated, modular units are used.
Typical inflows range from 2 to 200 m^3 per day. Critical design parameters include a hydraulic retention time (HRT) between 48 to 72 hours, upflow velocity of the wastewater below 0.6 m/h and the number of upflow chambers (3 to 6). The connection between the chambers can be designed either with vertical pipes or baffles. Accessibility to all chambers (through access ports) is necessary for maintenance. Usually, the biogas produced in an ABR through anaerobic digestion is not collected because of its insufficient amount. The tank should be vented to allow for controlled release of odorous and potentially harmful gases.

Appropriateness This technology is easily adaptable and can be applied at the household level, in small neighbourhoods or even in bigger catchment areas. It is most appropriate where a relatively constant amount of blackwater and greywater is generated. A (semi-) centralized ABR is appropriate when there is a pre-existing Conveyance technology, such as a Simplified Sewer (C.4).
This technology is suitable for areas where land may be limited since the tank is most commonly installed underground and requires a small area. However, a vacuum truck should be able to access the location because the sludge must be regularly removed (particularly from the settler).

ABRs can be installed in every type of climate, although the efficiency is lower in colder climates. They are not efficient at removing nutrients and pathogens. The effluent usually requires further treatment.

Health Aspects/Acceptance Under normal operating conditions, users do not come in contact with the influent or effluent. Effluent, scum and sludge must be handled with care as they contain high levels of pathogenic organisms. The effluent contains odorous compounds that may have to be removed in a further polishing step. Care should be taken to design and locate the facility such that odours do not bother community members.

Operation & Maintenance An ABR requires a start-up period of several months to reach full treatment capacity since the slow growing anaerobic biomass first needs to be established in the reactor. To reduce start-up time, the ABR can be inoculated with anaerobic bacteria, e.g., by adding fresh cow dung or Septic Tank sludge. The added stock of active bacteria can then multiply and adapt to the incoming wastewater. Because of the delicate ecology, care should be taken not to discharge harsh chemicals into the ABR.
Scum and sludge levels need to be monitored to ensure that the tank is functioning well. Process operation in general is not required, and maintenance is limited to the removal of accumulated sludge and scum every 1 to 3 years. This is best done using a Motorized Emptying and Transport technology (C.3). The desludging frequency depends on the chosen pre-treatment steps, as well as on the design of the ABR.
ABR tanks should be checked from time to time to ensure that they are watertight.

Pros & Cons
+ Resistant to organic and hydraulic shock loads
+ No electrical energy is required
+ Low operating costs
+ Long service life
+ High reduction of BOD
+ Low sludge production; the sludge is stabilized
+ Moderate area requirement (can be built underground)
- Requires expert design and construction
- Low reduction of pathogens and nutrients
- Effluent and sludge require further treatment and/or appropriate discharge

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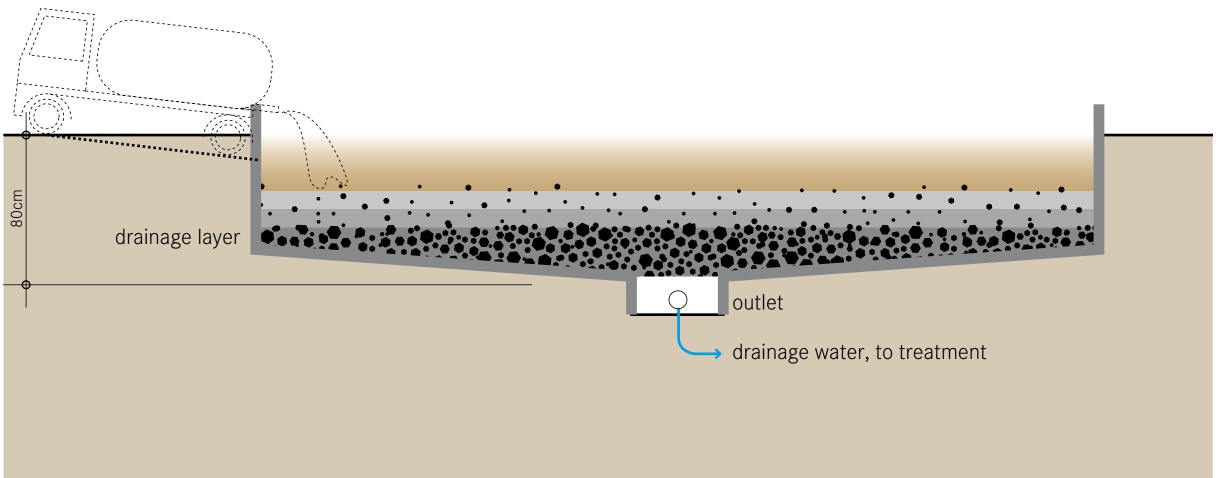
T.14

Unplanted Drying Beds

Applicable to:
Systems 1, 6-9

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



An unplanted drying bed is a simple, permeable bed that, when loaded with sludge, collects percolated leachate and allows the sludge to dry by evaporation. Approximately 50% to 80% of the sludge volume drains off as liquid or evaporates. The sludge, however, is not effectively stabilized or sanitized.

The bottom of the drying bed is lined with perforated pipes to drain the leachate away that percolates through the bed. On top of the pipes are layers of gravel and sand that support the sludge and allow the liquid to infiltrate and collect in the pipe. It should not be applied in layers that are too thick (maximum 20 cm), or the sludge will not dry effectively. The final moisture content after 10 to 15 days of drying should be approximately 60%. When the sludge is dried, it must be separated from the sand layer and transported for further treatment, end-use or final disposal. The leachate that is collected in the drainage pipes must also be treated properly, depending on where it is discharged.

Design Considerations The drainage pipes are covered by 3-5 graded layers of gravel and sand. The bottom layer should be coarse gravel and the top fine sand (0.1 to 0.5 mm effective grain size). The top sand layer should be 250 to 300 mm thick because some sand will be lost each time the sludge is removed.
To improve drying and percolation, sludge application can alternate between two or more beds. The inlet should be equipped with a splash plate to prevent erosion of the sand layer and to allow for even distribution of the sludge.
Designing unplanted drying beds has to consider future maintenance because ensuring access to people and trucks for pumping in the sludge and removing the dried sludge is essential.
If installed in wet climates, the facility should be covered by a roof and special caution should be given to prevent the inflow of surface runoff.

Appropriateness Sludge drying is an effective way to decrease the volume of sludge, which is especially important when it has to be transported elsewhere for further treatment, end-use or disposal. The technology is not effective at stabilizing the organic fraction or decreasing the pathogenic content. Further storage or treatment (e.g., Co-Composting, T.16) of the dried sludge might be required.

Unplanted drying beds are appropriate for small to medium communities with populations up to 100,000 people, but larger ones also exist for huge urban agglomerations. They are best suited for rural and peri-urban areas where there is inexpensive, available space situated far from homes and businesses. If designed to service urban areas, unplanted drying beds should be at the border of the community, but within economic reach for Motorized Emptying operators.

This is a low-cost option that can be installed in most hot and temperate climates. Excessive rain may prevent the sludge from properly drying.

Health Aspects/Acceptance Both the incoming and dried sludge are pathogenic; therefore, workers should be equipped with proper protection (boots, gloves, and clothing). The dried sludge and effluent are not sanitized and may require further treatment or storage, depending on the desired end-use.

The drying bed may cause a nuisance for nearby residents due to bad odours and the presence of flies. Thus, it should be located sufficiently away from residential areas.

Operation & Maintenance Trained staff for operation and maintenance is required to ensure proper functioning.

Dried sludge can be removed after 10 to 15 days, but this depends on the climate conditions. Because some sand is lost with every removal of sludge, the top layer must be replaced when it gets thin. The discharge area must be kept clean and the effluent drains should be regularly flushed.

Pros & Cons

+ Good dewatering efficiency, especially in dry and hot climates
+ Can be built and repaired with locally available materials
+ Relatively low capital costs; low operating costs
+ Simple operation, only infrequent attention required
+ No electrical energy is required
- Requires a large land area
- Odours and flies are normally noticeable
- Labour intensive removal
- Limited stabilization and pathogen reduction
- Requires expert design and construction
- Leachate requires further treatment

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