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Technical Brief:
Introduction to Fecal Sludge Management

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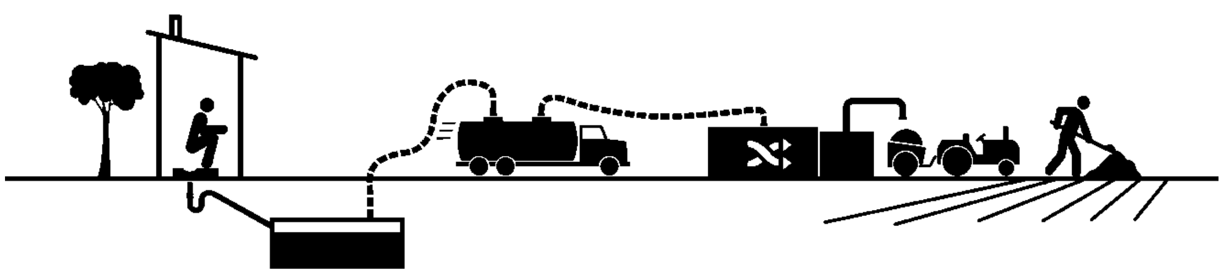


(Credit: The Bill & Melinda Gates Foundation)

Technical Brief:
Introduction to Fecal Sludge Management

1 Introduction

This Technical Brief introduces the importance and global need for fecal sludge management to realize public health, environmental, social, and economic benefits.

Great efforts are being made globally to reduce open defecation by building on-site sanitation technologies, like pit latrines and septic tanks. Yet, emptying full on-site sanitation technologies and safely managing the fecal sludge is an essential service that is often neglected. Households and institutions are lacking the knowledge, skills and services to manage the fecal sludge once the technology is full.

2.7 billion people around the world use on-site sanitation technologies that need fecal sludge management services (Strande, Ronteltap & Brdjanovic, 2014). Ideally, on-site sanitation technologies should be emptied in a safe and hygienic manner by well-equipped and protected workers who transport the sludge for treatment, use or disposal. However, in reality, most technologies are either abandoned or emptied using unsafe and unhygienic methods. Sludge is simply dumped by the home, in the street, or in nearby water sources.

Illegally dumping fecal sludge into a local water source

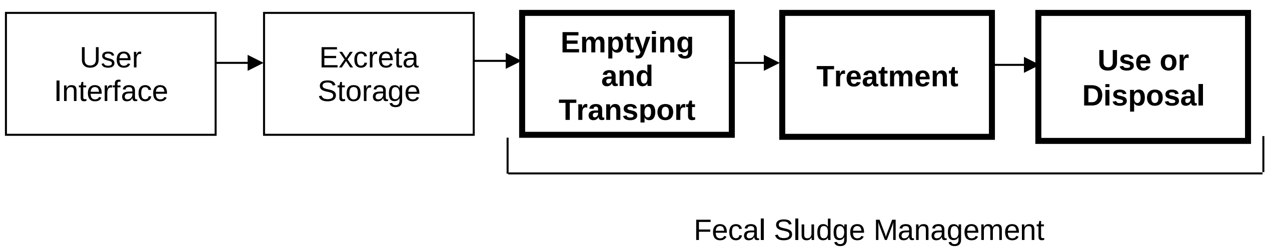
CAWST focuses on the planning, design, and implementation of on-site sanitation projects for low-income communities not connected to a sewer. For such communities, household or decentralized sanitation offers a hygienic and affordable solution.

CAWST's free, open content resources and schedule of international training workshops can be found at: https://resources.cawst.org and www.cawst.org/services/training.

2 What is Fecal Sludge Management?

A sanitation system deals with human excreta from the time it is generated until it is used or disposed of safely. Fecal sludge management includes emptying, transportation, treatment, and use or disposal of fecal sludge from an on-site sanitation technology (like a pit latrine or septic tank). It addresses the last three components of a sanitation system.

Sanitation System



Fecal sludge management is a relatively new term and field that is gaining rapid acknowledgement in the sanitation sector. The following definitions help explain the scope of fecal sludge management:

- **Fecal sludge** (also called sludge) is excreta from an on-site sanitation technology (like a pit latrine or septic tank) that may also contain used water, anal cleansing materials, and solid waste. Fecal sludge should not to be confused with wastewater that has been transported through a sewered system.
- **Excreta** is urine and feces that are not mixed with any flush water.
- An **on-site sanitation technology** is made up of the parts included in the first two components of a sanitation system: user interface and excreta storage. Excreta is collected and stored where it is produced (for example, a pit latrine, septic tank, aqua privy, and non-sewered public toilets). Often, the fecal sludge has to be transported off-site for treatment, use or disposal.

Simple pit latrine

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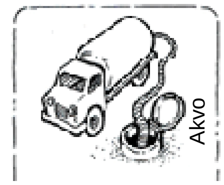
2.1 Emptying and Transport



Mechanized Emptying

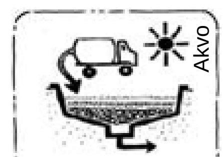
On-site sanitation technologies will fill up sooner or later. There are two types methods to collect fecal sludge from on-site sanitation technologies and transport it for treatment or safe disposal:

1. Manual emptying (using a bucket or hand pump)
2. Mechanized emptying (using a motorized pump or vacuum truck)

Once emptied, the fecal sludge must be safely transported to a treatment or disposal location. Again, there are various manual and mechanized vehicles ranging from pushcarts to pickup trucks to vacuum trucks.

Emptying and transporting fecal sludge is an essential service that is often neglected in sanitation projects. Ideally, on-site sanitation technologies should be emptied in a safe and hygienic manner by well-equipped and protected workers who transport the sludge to a treatment, use or disposal site. However, in reality, many on-site technologies are either abandoned or emptied using unsafe and unhygienic methods. Fecal sludge is simply dumped by the home, in the street, or in nearby water sources.

2.2 Treatment



Unplanted Drying Bed

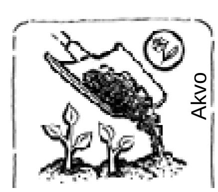
The type and level of treatment depends on the final goal for the fecal sludge (how it is to be used or disposed of). There are four different treatment objectives for fecal sludge: (1) pathogen inactivation, (2) stabilization, (3) dewatering, and (4) nutrient management. Each treatment objective has associated environmental, health, and logistics impacts.

Treatment technologies available for fecal sludge are in different stages of development:

- **Established**: There is experience in designing and operating the technologies for fecal sludge. For example, drying beds, settling-thickening, and co-composting.
- **Transferring**: Technologies are being adapted from wastewater treatment or another sector. For example, mechanical dewatering, anaerobic digestion, incineration, and thermal drying.
- **Innovative**: Technologies are being researched, developed and piloted. For example, alkaline and ammonia treatment, vermicomposting, and black soldier flies for animal protein.

2.3 Use or Disposal

The following are some options for using or disposing of urine and feces in ways that are the least harmful to people and the environment:



Use in Agriculture

- Use urine as a fertilizer
- Use treated fecal sludge and source-separated urine as a soil amendment in home gardens and agriculture to provide nutrients for plant growth and improve the physical qualities of soil

- Use treated fecal sludge as a soil amendment in: forestry, sod and turf growing, flower growing, landscaping, parks, golf courses, mine reclamation, landfill cover, or erosion control
- Use fecal sludge and source-separated urine as a source of nutrients and water for growing aquatic plants and fish (also known as aquaculture)
- Use fecal sludge as a source of protein for animal feed (for example, black soldier fly larvae)
- Use fecal sludge as a source of energy (for example, biogas and solid fuel)
- Dispose of fecal sludge by burying in a pit, trench or landfill
- Dispose of source-separated urine into the ground using a soak pit or infiltration trench

2.4 Risk Management

Fecal sludge management aims to reduce the risk of pathogen transmission and environmental contamination through using protective measures. These are actions, often called barriers or the multi-barrier approach, to prevent or eliminate a sanitation-related risk, or reduce it to an acceptable level (WHO, 2016).

Restricting access to a sludge treatment or disposal site

The more protective measures that are used, the lower the risk of pathogen transmission and environmental contamination. Fecal sludge management often focuses on treatment as a protective measure to reduce health risks. Yet, it is difficult to check the quality of treated sludge to ensure that it is safe and pathogen-free. There is always an environmental and health risk. It is therefore important that other health and safety measures are put in place, even when the sludge has been treated.

Table: Examples of Protective Measures in Fecal Sludge Management

Type of Protective Measure		**Examples of Protective Measure**
Treatment		• Inactivate pathogens in fecal sludge (for example, co-composting)
Non-treatment	Technical	• Crop selection: Fecal sludge is applied to only certain crops (for example, non-edible crops) • Pause period: Wait a certain period of time before harvesting crops grown with fecal sludge • Restrict access: Place a barrier (like a fence) to stop people from approaching a fecal sludge management area
	Behavioural	• Use personal protective equipment when handling fecal sludge (for example, boots, gloves, masks, and protective clothing) • Wash hands with soap after handling fecal sludge • Use good food hygiene when preparing foods grown with fecal sludge products

Protective measures can be difficult to put in place. They will be more or less efficient depending on various factors, such as local habits and available resources. For example, it may be more efficient to focus on covering fecal sludge with soil rather than wearing shoes if farmers work barefoot or if shoes are not available or affordable.

Identify risks and vulnerable groups before identifying and prioritizing protective measures. Generally, people who work with fecal sludge directly (like latrine pit emptiers, compost plant operators, farmers who use fecal sludge as a fertilizer) have a higher risk of getting sick from fecal pathogens than the general public. The four groups of people exposed to risks include the following:

1. **Workers**: People who empty and transport sludge, work at a treatment site or dispose of the sludge
2. **Farmers**: People who use fecal sludge to fertilize their fields.
3. **Consumers**: People who eat food that has been grown using fecal sludge as a fertilizer.
4. **Local community**: People that live in a community near fecal sludge treatment technologies.

(WHO, 2016)

3 The Importance of Fecal Sludge Management

Failing to properly manage fecal sludge is directly responsible for adverse effects on public health and the environment worldwide. It is not just enough to build a latrine to ensure good sanitation and protect public health. Without fecal sludge management services, untreated sludge enters the environment and contaminates drinking water sources. This is often the case when latrines are left to overflow or fecal sludge is illegally dumped into the environment.

Excreta is a major source of pathogens – microorganisms such as bacteria, viruses, protozoa and helminths that cause disease. Pathogens in untreated excreta can survive a long time in the environment. They can transmit diseases to people and animals through direct contact and contaminated soil, food, and water.

Diarrhea is one of the leading diseases that cause death and illness. Globally, about 361,000 children die every year from diarrheal diseases linked to poor WASH (Prüss-Ustün et al., 2014). That's about 1,000 children under five every day. For every child that dies from diarrhea, countless others suffer from poor health and lost educational opportunities leading to poverty in adulthood.

In addition to health and environmental benefits, the economic benefits of improved sanitation are also persuasive. Improved sanitation in developing countries typically yields about US$5.50 worth of benefits for every dollar spent (Hutton, 2005).

The benefits of improved sanitation also extend beyond better health and economics. No one wants to live, work or go to school in dirty, smelly, and unsanitary conditions. Improved sanitation also contributes to the general well-being of a population.

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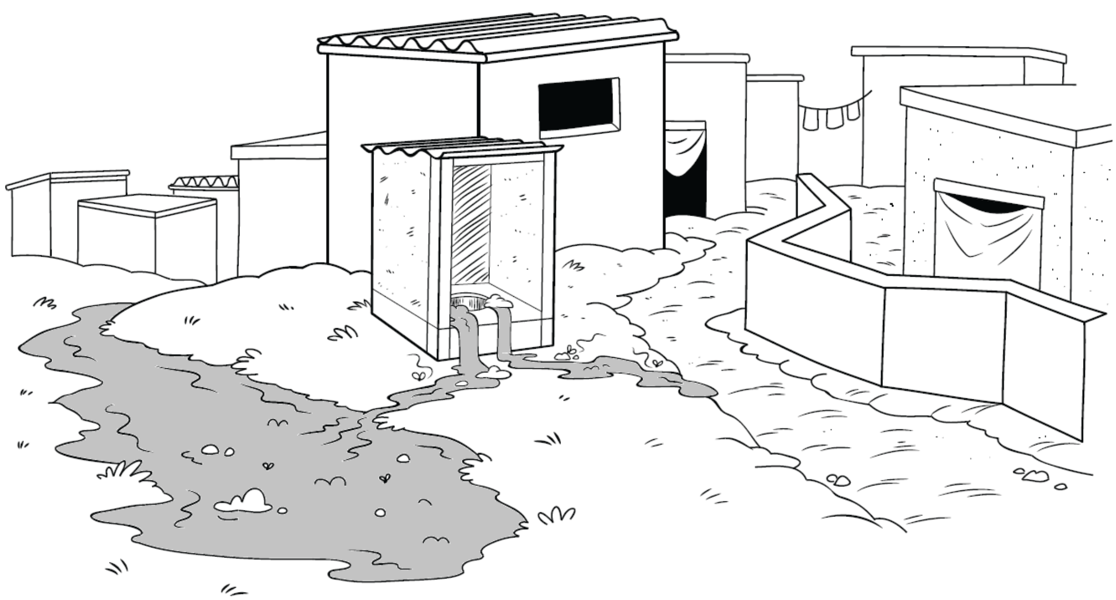
The Joint Monitoring Programme (JMP) for water supply and sanitation measures the progress towards achieving the Sanitation Development Goal (SDG) target of ensuring availability and sustainable management of water and sanitation for all by 2030 (Goal 6). The goal includes the whole sanitation system. This is a move from the Millennium Development Goals (MDGs) that focused on access to improved sanitation. The term fecal sludge management is not directly used in the SDG Goal 6, but it is covered by "safely managed sanitation services". This is defined as excreta that is safely disposed in situ or transported and treated off-site.

Poor Fecal Sludge Management = Open Defecation?

Imagine a town of 5,000 people using pit latrines. Full pits are emptied manually. The untreated sludge is dumped into the nearby river. Is this any different from open defecation?



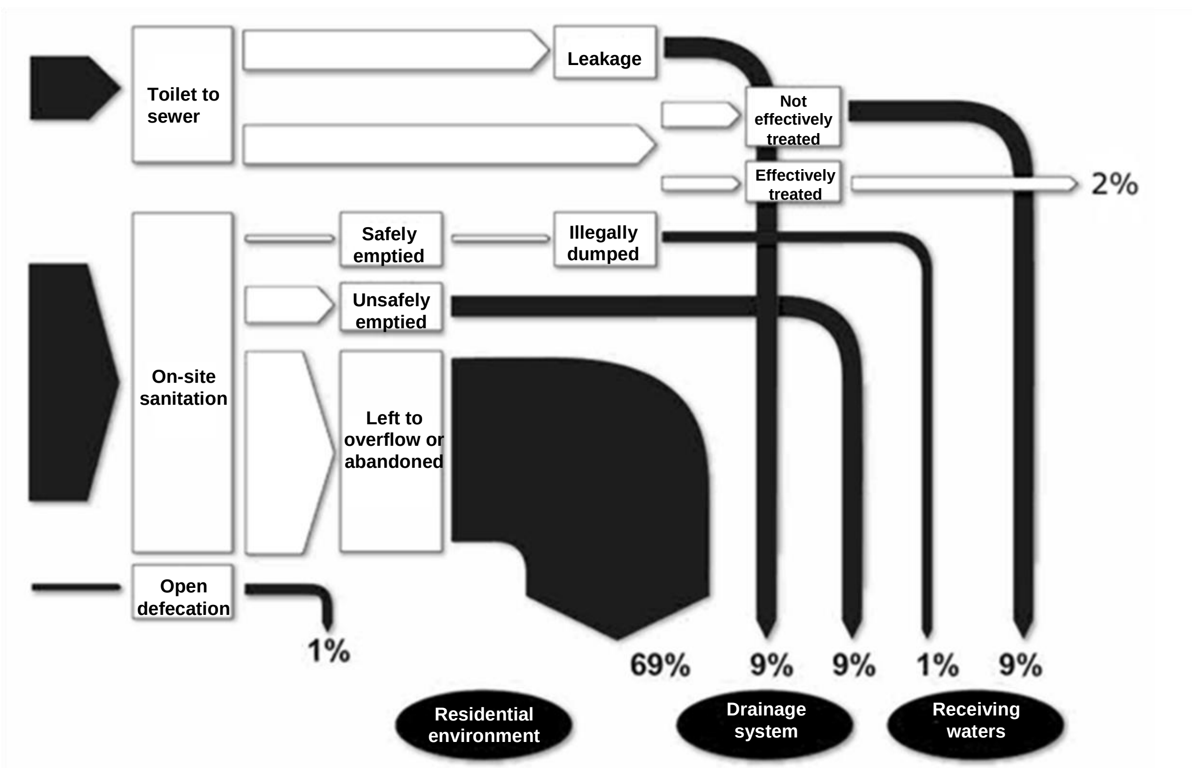
An overflowing latrine impacts the home and community

Case Study: Fecal Sludge Management in Dhaka, Bangladesh

Dhaka has made a lot of efforts to reduce open defecation. As a result, only 1% of the population still defecates in the open. 79% of people use on-site sanitation technologies and 20% are connected to a sewer.

However, all of the fecal sludge from on-site sanitation technologies is disposed of untreated into the environment. It is either dumped around people's homes, into drainage systems, or into water sources.

- 87.3% of on-site sanitation technologies are left to overflow or abandoned.
- 11.4% of on-site sanitation technologies are unsafely emptied.
- 1.3 % of on-site sanitation technologies are safely emptied, but the fecal sludge is illegally dumped .



(Blackett, Hawkins & Heymans, 2014)

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4 The Global Need for Fecal Sludge Management

2.7 billion people around the world use on-site sanitation technologies that need fecal sludge management services (Strande et al., 2014). The greatest numbers are in Eastern Asia with 1.1 billion people, Southern Asia with 593 million people, and Sub-Saharan Africa with 439 million. These are households and communities using latrines without access to or unable to afford fecal sludge management services.

If present sanitation trends continue, the number of people needing fecal sludge management services will rise to 5 billion people by 2030 (Strande et al., 2014). This number could increase even faster as water scarcity becomes more severe. Sewered systems use a lot of water to flush wastewater to a treatment facility. As water becomes less available, it will become more challenging to flush everything away through sewers. Households will have to use on-site sanitation technologies instead of being linked to a sewered system.

For years, on-site sanitation has been considered as a temporary solution until a sewered system is constructed (Strande, Ronteltap & Brdjanovic, 2014). In a sewered system, excreta and flush water from toilets, as well as other used water from laundry, kitchens and bathing, is transported from the home by a direct connection to a system of pipes (sewers) buried deep underground. Ideally, the wastewater is sent to a treatment facility. Well-constructed and maintained sewered systems with wastewater treatment facilities can provide effective and efficient services.

Sewered systems have been constructed in many parts of the world, particularly in high-income countries. However, for many low- and middle-income communities, particularly in developing countries, installing a sewered system is not a feasible option due to the complexity, high cost, and need for a piped water supply. For such communities, on-site sanitation offers a hygienic and affordable solution (Franceys, Pickford & Reed, 1992).

Sanitation planners have come to realize that sewered systems are an inappropriate technology to manage excreta in many parts of low- and middle-income countries. This has led to a shift in sanitation planning. Implementers are now accepting on-site sanitation as an appropriate, sustainable, and affordable solution as long as fecal sludge emptying, transport, treatment and disposal or use services are available and managed correctly (Strande et al., 2014).

On-site sanitation is often considered as a solution in only rural areas. However, on-site sanitation is also very common in urban areas. In fact, one billion people using on-site sanitation live in urban areas (Strande et al., 2014). The wealthy neighbourhoods are often the only parts of a city linked to a sewered system. Governments are often unwilling to invest funds to install a sewered system in lower-income neighbourhoods. This can be for various reasons such as land ownership, affordability and instability. Households in these lower-income neighbourhoods usually have to build their own on-site technology, like a pit latrine or septic tank. When their latrines fill up, they have to manually empty them or pay for an informal emptying service.

Although some neighborhoods have informal services for emptying and transportation, services for treating sludge rarely exist.

Table: Why Are Sewered Systems Not Always Appropriate to Manage Excreta?

Advantages	Limitations
• Convenient for households: the excreta is almost immediately removed from their property and is no longer theirs to manage. • Easy to control and test: all the excreta is centralized. • Well-constructed and maintained sewered systems with wastewater treatment facilities can reduce environmental contamination and protect public health	• Resource intensive: a large amount of water is needed year-round • High technical skills required • High capital cost • High operation and maintenance costs • If not functioning correctly, can cause significant environmental contamination and public health risk

5 Implementation Challenges

Fecal sludge management is an urgent issue in many parts of the world. Unfortunately, it is not that simple and implementers have many challenges. These result from the complexity of the process. There are various stakeholders to involve including the household users, informal and formal private sector, government, nongovernmental organizations (NGOs) and community-based organizations (CBOs). Some of the key challenges include:

- **Accessibility:** On-site sanitation technologies are not always accessible to emptying services. They can also be located too far from a service provider. It is not worth the cost of transportation or the service provider's time. The roads can also be too narrow and poorly constructed for emptying vehicles. Furthermore, people constructing on-site sanitation technologies often do not take into account the emptying component. It can be difficult to have direct access to the latrine pit or septic tank.
- **Affordability:** Many households cannot afford emptying services. They rely on informal private services to manually empty their on-site sanitation technology. Many manual transport services also cannot afford to take sludge to a treatment site that is located far away. Instead, they choose to dump the untreated sludge close to the on-site sanitation technology and directly into the environment.
- **Investment:** There is a lack of fecal sludge management services because there is a need for investment in construction, operation, and maintenance. Many fecal sludge technologies stop functioning because there is little to no funding available for long-term operation and maintenance.
- **Policy:** Policy makers still focus on sewered systems rather than on-site sanitation, which is often considered a temporary solution. Therefore, not many countries have a policy on fecal sludge management. As a result, fecal sludge management is often unplanned, unreliable, and operated by informal private services.
- **Legal Frameworks:** Laws on fecal sludge management are non-existent or weak. This leads to illegal dumping of untreated sludge into the environment. In countries where there are laws, there have been challenges with enforcing them (Johansson & Kvarnstrom, 2005).

- **Knowledge and Skills:** Compared to wastewater management, fecal sludge management has only recently gained acknowledgement. There is less research and lessons learned in this field. As well, there are few examples of success. There is a gap in knowledge on how to ensure fecal sludge is safe to dispose of or use (Strande et al., 2014).

6 International Guidelines, National Law and Policy

Over 66% of countries have recognized the human right to sanitation in their constitution or legislation (GLAAS, 2014). Recognizing the human right to sanitation is a good start towards improving access to sanitation. Governments are held accountable by international human rights law. However, to sustain sanitation, governments must also develop national legislation and supporting policy. They must also ensure implementation and enforcement of these laws and policies. This has proved to be a difficult task globally.

One of the reasons for this struggle is because the sanitation system is included in different pieces of legislation. Components of the sanitation system are often spread across environmental protection, public health, construction, and agriculture legislation. This leads to gaps and overlaps in the legislation (Johansson & Kvarnstrom, 2005).

Once the national sanitation laws and policies are established, they need to translate into local action. A government is usually made of different levels. Many governments, for example, are composed of a national, regional and local level government. Legislation and policy must state clearly the roles of the different levels of government, which is not often the case (Johansson & Kvarnstrom, 2005). The lack of delegation, capacity and resources weakens the implementation of legislation and policy.

Questions that need to be clearly answered by national governments include:

- Who takes the lead?
- Who regulates?
- Who monitors?
- Who enforces?

Case Study: Ugandan Law and Policy on Sanitation

- The Constitution of Uganda (1995) states that it is a fundamental right for every Ugandan citizen to have access to a clean and healthy environment.
- Local Government Act (1997) defines the roles of local councils in providing and promoting sanitation and hygiene services at community and household levels.
- The Public Health Act (1935) states that every citizen is obliged to have suitable access to an excreta disposal facility in his or her home and at work places.
- National Health Sector Policy (2009 Draft) states that sanitation is one of the major determinants of health in Uganda.
- Environmental Health Policy states that sanitation systems are to be designed as to reduce the environmental impact of unmanaged human waste disposal.
- The Water Statue (1995) is the fundamental code for the use, protection and management of water resources and water supply; and for the constitution of water and sewerage authorities for the various towns and cities.
- The Waste Discharge Regulations (1998) defines standards for water discharged into water or onto land.

(Johansson & Kvarnstrom, 2005)

The World Health Organization (WHO) released the Guidelines for Safe Use of Wastewater, Excreta and Greywater in 2006. They provide a comprehensive framework for managing health risks associated with using human waste in agriculture and aquaculture. The Guidelines were designed to assist in developing national and international approaches (like policies and legislation). They also provide a framework for national and local decision making to identify and manage health risk. Crucially, the Guidelines recognize that changes in sanitation policy and investment in improvements, be they capital works, operations or behavioural measures, involve multiple actors and take time (WHO, 2016).

The Sanitation Safety Planning Manual was released by the WHO in 2016 to provide practical step-by-step guidance to assist in the implementation of the 2006 Guidelines. The Manual assists users to implement the Guidelines by providing a structure to bring together actors from different sectors to identify health risks in a sanitation system and agree on improvements and regular monitoring. The concepts of coordination and incremental improvement over time are central to the sanitation safety planning approach (WHO, 2016).

7 The Knowledge Gap

Fecal sludge management has only recently received the attention it deserves. In terms of experience and research, fecal sludge management is at least a hundred years behind wastewater management (Strande et al., 2014). There is an increasing amount of research conducted on this topic, but it is important to recognize the knowledge gap and limited experience. The gap includes:

- **The science behind fecal sludge management**: There are still a lot of unknowns such as fecal sludge characteristics and its variability. There is still no standardized methodology, for example, to characterize and quantify fecal sludge. This limits knowledge particularly on treatment and use of fecal sludge. This lack of understanding has led many engineers to manage fecal sludge like wastewater, leading to major technical failures.
- **Viable implementation models**: There are few examples of successful implementation of fecal sludge management across the sanitation sector (civil society, government, private sector). There is still a lot of debate on how to properly manage the whole sanitation system, and which stakeholders are most appropriate for the different roles.
- **Knowledge and skills of stakeholders**: Many stakeholders including civil society, government and the private sector do not have the knowledge and skills to implement strong fecal sludge management systems.
- **Enforced policy and legal framework**: Many countries are lacking a policy and legal framework on fecal sludge management. Policy and laws are often based on developed countries and hence focus on sewered systems. Fecal sludge management is therefore often unplanned, unreliable, and operated by informal private services. This leads to illegal dumping of untreated faecal sludge into the environment and increases health risk. Even in places where there is a legal framework, enforcement is weak.

However, the knowledge gap is starting to close. Here are some of the key groups and meetings leading the fecal sludge management sector:

- **The Department of Water and Sanitation in Developing Countries (Sandec) at the Swiss Federal Institute of Aquatic Science and Technology (Eawag):** Sandec's research on excreta and wastewater management focuses on three main challenges: (1) optimization of treatment technologies, (2) innovation in resource recovery, and (3) methods for sustainable systems level implementation. Available at: www.sandec.ch
- **University of Kwazulu-Natal:** The Pollution Research Group established in 1973 works on various projects relating to pit latrines, diversion toilets and generally closing the loop. Available at: http://prg.ukzn.ac.za/
- **SuSanA:** The Sustainable Sanitation Alliance is an open international alliance with members who share a common vision on sustainable sanitation. They are dedicated to understanding viable and sustainable sanitation solutions. Available at: www.susana.org/en/
- **Fecal Sludge Management Conference:** Gathers specialists and implementers of fecal sludge management to share experiences and best practices. The conference aims to present practical innovative solutions that can be applied at scale in the world's rapidly growing cities. Topics include: How to develop tools to assess the generation of fecal sludge, the pathways it takes from containment to disposal, and the constraints to

establishing an effective chain of services to manage it. There have been three conferences so far since the first one in 2011. Available at: www.fsm3.org/

8 Definitions

Disposal: The return of waste to the environment, ideally in a way that is least harmful to public health and the environment.

Excreta: Urine and feces not mixed with any flush water.

Fecal sludge: Also called sludge. Excreta from an on-site sanitation technology (like a pit latrine or septic tank) that may also contain used water, anal cleansing materials, and solid waste.

Fecal sludge management: Includes the emptying, transport, treatment, and safe use or disposal of fecal sludge from an on-site sanitation technology (like a pit latrine or septic tank). Some people also include storage in the definition of fecal sludge management.

Guidelines: International recommendations to help governments set national standards or determine a course of action. Guidelines are not mandatory.

Legislation: A group of laws or the action of making laws.

Non-sewered system: Also called on-plot or on-site sanitation. A sanitation system in which excreta and used water are collected and stored on the location where it is produced. Often, the fecal sludge has to be transported off-site for treatment, use or disposal.

Nutrient: Any substance that is used for growth. Nitrogen (N), phosphorus (P), and potassium (K) are the main nutrients in agricultural fertilizers.

On-site sanitation: Also called on-plot sanitation or non-sewered system. A sanitation system in which excreta and used water are collected and stored or treated on the location where it is generated. Often, the fecal sludge has to be transported off-site for treatment, use or disposal.

On-site sanitation technology: Also known as a latrine. An on-site sanitation technology is made up of the parts included in the first two components of a sanitation system: user interface and excreta storage. Excreta is collected and stored where it is produced (for example, a pit latrine, septic tank, aqua privy, and non-sewered public toilets). Often, the fecal sludge has to be transported off-site for treatment, use or disposal.

Pathogen: An organism that causes disease.

Policy: A government plan to guide and determine future decisions.

Sanitation: The safe management of human excreta. The main objective is to protect and promote public health by providing a clean environment and breaking the cycle of disease.

Sanitation system: Also called a sanitation chain or sanitation service chain. A collection of technologies and services that deals with human excreta from the time it is generated until it is used or disposed of safely. A sanitation system includes five components: (1) user interface, (2) excreta storage, (3) emptying and transporting fecal sludge, (4) fecal sludge treatment, and (5) fecal sludge use or disposal. A sanitation system also includes the management, operation and maintenance required to ensure that the system functions safely and sustainably. The components or functions within the sanitation system may be named differently depending on the local context or organization.

Sewered system: Also called a sewer system, sewerage system, sewers, connected sanitation, and networked sanitation. A sanitation system that transports wastewater through a pipe network (like a simplified sewer, solids free sewer or conventional sewer) to another location for treatment, use or discharge. This includes centralized systems and decentralized wastewater treatment systems.

Soil amendment: Anything mixed into soil to improve soil quality and support healthy plant growth. Fertilizers and soil conditioners are two types of soil amendments. Fertilizers add nutrients to the soil that plants need to grow. Soil conditioners improve the physical soil structure.

Use: The use of waste as a beneficial resource. For example, using treated fecal sludge as a soil conditioner in agriculture.

Wastewater: Used water from any combination of domestic, industrial, commercial or agricultural activities, surface runoff (stormwater), and any sewer inflow (infiltration). Wastewater can be managed on-site or off-site. Wastewater managed off-site is often called sewage.

9 Additional Resources

CAWST Sanitation Resources. Available at: https://resources.cawst.org

- CAWST's education and training resources are available on a variety of sanitation topics including environmental sanitation; latrine design, siting and construction; fecal sludge management; and sanitation project implementation.

Faecal Sludge Management: Systems Approach for Implementation and Operation. Strande, L., Ronteltap, M. & Brdjanovic, D. (2014). London, UK: IWA Publishing. Available at: www.sandec.ch/fsm_book

- This is the first book dedicated to faecal sludge management. It summarizes the most recent research in this rapidly evolving field, and focuses on technology, management and planning. It addresses faecal sludge collection and transport, treatment, and the final end use. The book also goes into detail on operational, institutional and financial aspects, and gives guidance on integrated planning involving all stakeholders. It is freely available online in English and Spanish, and is coming out in French in 2017.

Compendium of Sanitation Systems and Technologies. Tilley, E., Ulrich, L., Lüthi, C., Reymond, P. and Zurbrügg, C. (2014). 2nd Revised Edition. Eawag: Swiss Federal Institute of Aquatic Science and Technology, Dübendorf, Switzerland. Available at: www.eawag.ch/forschung/sandec/publikationen/compendium_e

- The Compendium presents the concept of sanitation systems together with detailed information about sanitation technologies for each component of sanitation systems. The document targets engineers, planners and other professionals who are familiar with sanitation technologies and processes. However, it is also a useful document for non-experts to learn about the main advantages and limitations of different technologies and the appropriateness of different systems.

- The e-Compendium, is an online, interactive version of the Compendium, complete with a tool for combining technologies into a complete sanitation system. Available at: http://ecompendium.sswm.info

Sanitation Safety Planning: Manual for Safe Use and Disposal of Wastewater, Greywater and Excreta. World Health Organization (2016). Available at: http://apps.who.int/iris/bitstream/10665/171753/1/9789241549240_eng.pdf?ua=1

- This Manual provides practical step-by-step guidance to assist in the implementation of the 2006 WHO Guidelines for Safe Use of Wastewater, Excreta and Greywater. Sanitation Safety Planning is a risk based management tool for sanitation systems. It provides a structure to bring together actors from different sectors to identify health risks in a sanitation system and agree on improvements and regular monitoring.

Sustainable Sanitation Alliance (SuSanA). Available at: www.susana.org

- SuSanA is an open international network of members who share a common vision on sustainable sanitation. SuSanA works as a coordination platform, working platform, sounding board, contributor to the policy dialogue on sustainable sanitation, and as a catalyst. The SuSanA website provides extensive resources including publications, case studies, photos and videos and a discussion forum targeted at practitioners, educators and researchers.

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Akvo images can be retrieved from http://akvopedia.org/wiki/Main_Page

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Technical Brief: What is Fecal Sludge?

Contents

1 Introduction

It is necessary to understand the characteristics and quantities of fecal sludge from on-site sanitation technologies, like a pit latrine or septic tank. This information is essential to plan and design appropriate fecal sludge management options.

The first step is to know what fecal sludge is. Where does it come from? What is it made of? How much is there? Fecal sludge from one on-site sanitation technology can be very different than sludge from another technology. It is highly variable in consistency, concentration, and quantity. The characteristics and quantities of fecal sludge depend on various technical, operational, and environmental factors.

Characterizing and quantifying fecal sludge is often overlooked because implementers are not aware of its importance. As well, fecal sludge is often still treated like wastewater despite differences in their characteristics. With more research and pilot projects, the sanitation sector will grow its capacities and knowledge on this topic. Guidelines or standards for characterizing and quantifying fecal sludge will also be developed.

This Technical Brief defines and explains the differences between excreta, fecal sludge and wastewater. It also explains the variability of fecal sludge characteristics and discusses the challenges in reliable fecal sludge characterization and quantification.

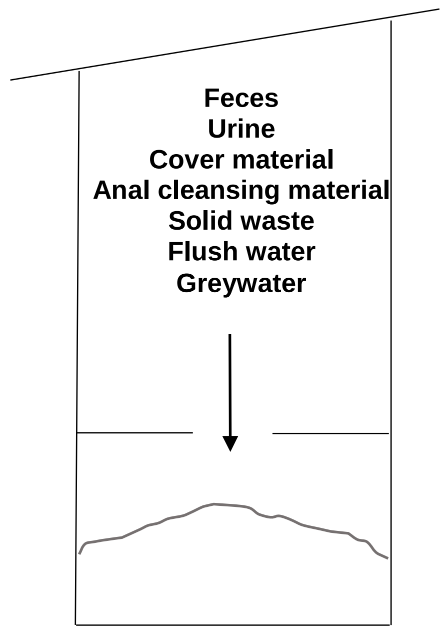
Fecal sludge collected in a pit latrine

CAWST focuses on the planning, design, and implementation of sanitation projects for low-income communities not connected to a sewered system. For such communities, household or decentralized sanitation offers a hygienic and affordable solution.

CAWST's free, open content resources and schedule of international training workshops can be found at: https://resources.cawst.org and www.cawst.org/services/training.

2 What is Fecal Sludge?

Fecal sludge is excreta from an on-site sanitation technology (like a pit latrine or septic tank) that may also contain used water (for example, flush water, greywater, anal cleansing water) and other anal cleansing materials (for example, paper). In a composting latrine, it will also include cover material (like ash or sawdust). As well, fecal sludge may have solid waste that is often disposed in a latrine.



Different components of fecal sludge

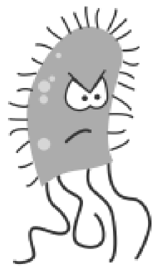
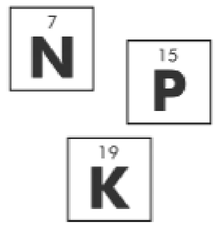
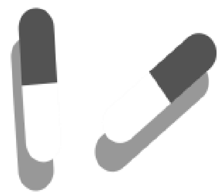
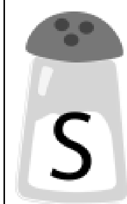
Excreta
= Urine + Feces

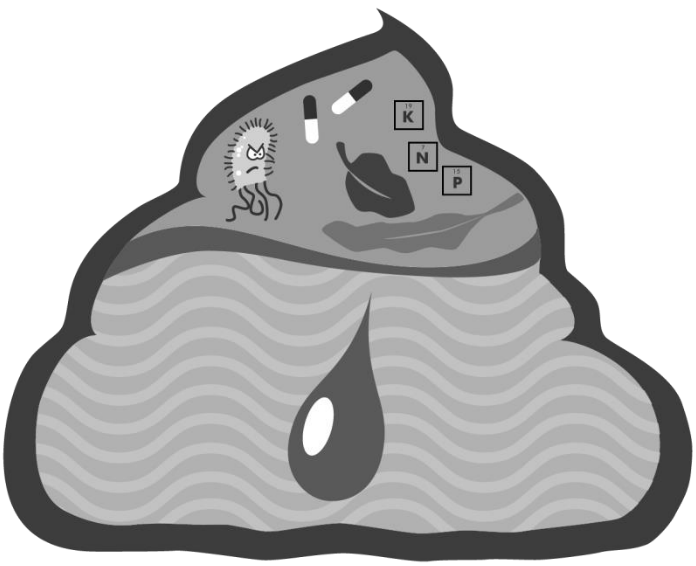
Fecal Sludge
= Excreta + Flush water + Anal cleansing material + Solid waste
↓
Collected in an on-site sanitation technology (like a pit latrine or septic tank)

Wastewater
= Excreta + Flush water + Anal cleansing material
↓
Transported through a sewered system

3 What is Excreta?

Excreta is made up of both feces and urine. The following are the main components of feces and urine:

Water	Organic Material	Pathogens	Nutrients	Trace Organics	Salt
					



Feces from a healthy person

Urine from a healthy person

3.1 Water

Both urine and feces are largely made of water. On average, 91-96 % of urine is water and 75% of feces are water (Rose, Parker, Jefferson & Cartmell, 2015). The amount of water excreted will mainly depend on how much liquid a person drinks, how much they sweat, their diet and age. The rest are solids.

3.2 Organic Material

Organic material comes from the remains of living organisms such as plants and animals. When we have a meal that contains vegetables and meat, we are eating organic material. This material goes through our digestive system. Some of the organic material is digested and is used as energy. The organic material that is not digested is excreted through feces and urine.

- 25% of feces are solids, of which 84-93% is organic material. This organic material includes undigested plants, nitrogen, fats, dead or live microorganisms and some carbohydrates. The rest of the solids are inorganic solids which include calcium phosphates, iron phosphates and other body fluids (Rose et al., 2015).
- 4-9 % of urine is dissolved and suspended solids, of which 65-85% is organic material. The main component of the organic material is urea (Rose et al., 2015).

How Much Organic Material is in Excreta?

Oxygen demand can be measured as an indicator of the amount of organic material in excreta. This is the amount of oxygen needed for microorganisms to digest all the organic material. This is known as biological oxygen demand (BOD) and it is measured in mg/L. The more organic material, the more oxygen microorganisms will need to fully digest it, and the higher the BOD. To measure BOD, a sample of excreta or urine is taken and tested using laboratory methods.

Pristine river:	1 mg/L (S.K. Gupta, 2011)
Moderately polluted river:	2 to 8 mg/L (S.K. Gupta, 2011)
Feces:	14,000 to 33,500 mg/L (Rose et al., 2015)
Fecal sludge from septic tanks:	840 to 2,600 mg/L (Koné & Strauss, 2004)
Fecal sludge from public toilets:	up to 7,600 mg/L (Koné & Strauss, 2004)

3.3 Nutrients

Nutrients are found in the food we eat. They go through our digestive system where some are used by our bodies and others are excreted through our urine and feces. Humans need nutrients to grow and stay healthy, particularly children. However, as an adult, our bodies excrete most nutrients. The main nutrients in fecal sludge are:

- Nitrogen (N)
- Phosphorous (P)
- Potassium (K)

Most of these nutrients are excreted through our urine, and only some are found in our feces. The following table shows the percentage of each nutrient that is excreted in urine and in feces.

Table: Percentage of Nutrients in Urine and Feces

Nutrient	Urine (%)	Feces (%)
Nitrogen	88	12
Phosphorous	67	33
Potassium	73	27

(Jonsson & Vinneras, 2004)

Nutrients: Fertilizer and Pollutant?

Nitrogen, phosphorous, and potassium are needed for plant growth. Farmers apply these nutrients onto their fields to increase crop yield. However, these nutrients can also infiltrate through the soil into the groundwater, or be transported by rainwater runoff to surface water bodies. They can contaminate both drinking water and the environment.

High concentrations of nutrients and organic material in surface water can damage the aquatic ecosystem and be disruptive to livelihoods (for example, fishing and tourism). Algae in the water feed on the nutrients and reproduce rapidly, called an algal bloom. The algae blocks the sunlight from penetrating the water, and other aquatic plants are unable to grow. When the algae dies and is eaten by other organisms, the oxygen in the water is used up and aquatic organisms (like fish) suffocate. This is known as eutrophication. In fresh water systems, phosphorous is the limiting nutrient whereas in salt water it is nitrogen.

Nutrients can also contaminate drinking water and impact our health. For example, nitrates (a form of nitrogen) in drinking water can cause methemoglobinemia, a condition which decreases the amount of oxygen transported through our blood. Infants who are bottle fed with formula prepared with nitrate contaminated drinking water are most at risk. See CAWST's Fact Sheets on the Chemical Parameters of Drinking Water Quality for more information about nitrogen.

3.4 Pathogens

Excreta naturally contains many living things. Some are harmless or even beneficial, but others can cause illness. Living things that cause disease are also known as pathogens. They are sometimes called other names, such as microorganisms, microbes or bugs, depending on the local language and country.

The number of pathogens in feces is generally much higher than in urine. Urine is normally sterile (contains no pathogens) when it leaves the human body. There are only a few pathogens, such as *Schistosoma haematobium* and *Salmonella typhi*, which can be excreted in urine. However, most pathogens found in urine are caused by fecal cross-contamination. This means the urine came into contact with feces. For example, the VUNA (Valorisation of Urine Nutrients in Africa) project, which aimed to recover nutrients from urine, found that urine collected from urine-diverting toilets was frequently cross-contaminated with feces (Etter, Udert & Gounden, 2015)

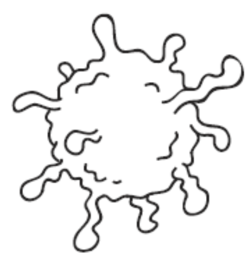
There are four different categories of pathogens: bacteria, viruses, protozoa, and helminths. Each will be discussed in the following sections.

Table: Examples of Fecal Pathogens, Illnesses and Symptoms

Pathogen Group	Illness	Symptoms
Bacteria	Cholera	Watery diarrhea, severe dehydration
	E. coli infection	Mild to severe diarrhea
	Typhoid fever	Headache, fever, nausea, vomiting, paralysis
Viruses	Hepatitis A and E	Fever, nausea, stomach pain, jaundice, anemia
	Rotavirus	Nausea, vomiting, diarrhea
Protozoa	Cryptosporidiosis	Watery diarrhea, stomach cramps and pain
	Giardiasis	Diarrhea, abdominal cramps, weight loss
Helminths	Ascariasis	Doesn't always have symptoms; sometimes abdominal pain, coughing
	Hookworm	Doesn't always have symptoms; sometimes stomach pain, anemia, local itching
	Schistosomiasis	Stunting and anemia in children, flu-like symptoms, painful urination, liver and intestinal pains

(Heymann, 2015)

3.4.1 Viruses



Viruses are the smallest microorganisms. Viruses are unable to reproduce by themselves and must use another living organism to make more viruses. Nonetheless, in the right conditions viruses can survive for months. Different viruses are more or less resistant to various environmental conditions. Even different strains of viruses have different levels of resistance which makes it difficult to monitor virus die-off.

The Hepatitis A and E viruses are transmitted mainly through fecal contamination of food and drinking water. Every year there are an estimated 20 million Hepatitis E infections and 56, 600 Hepatitis E-related deaths (WHO, 2015a). Hepatitis A occurs sporadically and in epidemics worldwide. It is one of the most frequent causes of foodborne infection. Almost everyone recovers fully from Hepatitis A (WHO, 2015b).

Is HIV Transmitted in Excreta?

HIV (human immunodeficiency virus) is not transmitted by feces and urine (Fan, Conner & Villarreal, 2011). However, HIV can be transmitted if feces and urine contain blood. Blood can be found in excreta when there is internal bleeding, menstruation or cuts.

Is the Ebola Virus in Excreta?

Ebola is a virus that spreads through person-to-person transmission through direct contact of broken skin and mucous membranes with blood and other body fluids, such as feces and urine. Transmission can occur through direct contact with these body fluids, or through touching fomites (inanimate objects such as the floor, utensils, and bed linens) that have recently been contaminated with infected body fluids.

The characteristics of the Ebola virus suggest that it is likely to be relatively fragile in the environment. The virus is unlikely to survive for extended periods outside of the body. Nonetheless, excreta from an infected individual should be treated as a biohazard.

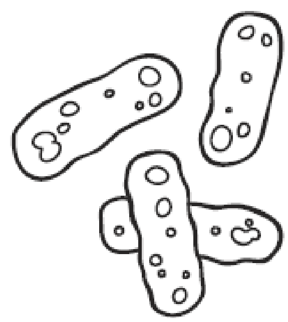
The World Health Organization provides specific recommendations for managing excreta from Ebola infected communities. Of particular importance are the following actions:

1. Keeping excreta separated from drinking water sources
2. Handwashing with soap
3. Containing excreta so that it is effectively separated from human contact

(World Health Organization, 2014a)

3.4.2 Bacteria

Bacteria are very small single-celled organisms that are present everywhere and are the most common living things found in human and animal feces.



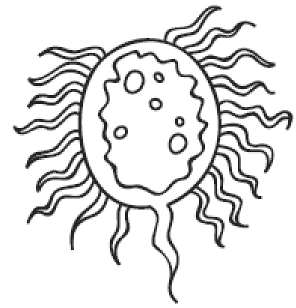
Diarrhea is a major symptom of the most common water-related diseases caused by pathogenic bacteria. These diseases include cholera, *E. coli* infection and typhoid fever. About 361,000 children die every year from diarrheal diseases linked to poor WASH (Prüss-Ustün et al., 2014). That’s about 1,000 children under five every day.

Cholera is an acute diarrheal disease that can kill within hours if left untreated. It is no longer an issue in countries that have basic water, hygiene and sanitation standards. However, it is still a problem where access to safe drinking water and adequate sanitation practices are limited. Researchers have estimated that there are 1.4 to 4.3 million cases, and 28,000 to 142,000 deaths worldwide due to cholera every year (WHO, 2015c).

Escherichia coli (E. coli) is a group of bacteria, some of which are pathogenic and cause disease. Enterotoxigenic strains (ETEC) of *E. coli* are among the most important pathogens causing dehydrating diarrhea in infants and children under the age of four in developing countries (Heymann, 2015).

Typhoid fever is a waterborne disease that is caused by a bacteria called *Salmonella typhi*. Typhoid fever is found worldwide. It causes about 27 million cases and 210,000 deaths each year (Heymann, 2015).

3.4.3 Protozoa



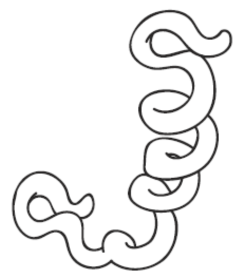
Protozoa are larger than bacteria and viruses. Some protozoa are parasites that need a living host to survive. They weaken the host by using up the host's food and energy, damaging its internal organs or causing immune reactions.

Amoeba, cryptosporidium and giardia are some of the pathogenic protozoa found in water that can cause diarrhea. They are found mainly in tropical countries.

Some protozoa like cryptosporidium are able to form cysts which allow them to stay alive without a living host and to survive in harsh environments. The protozoa cysts become active once the environmental conditions are optimal for their development.

3.4.4 Helminths

Helminths are worms. Helminths include nematodes (roundworms), cestodes (flat worms), and trematodes (flukes). Many helminths can live for several years in the human body.



Some helminth infections are transmitted by eggs present in human and animal feces, which in turn contaminate soil in areas where sanitation is poor. Soil-transmitted helminth infections are among the most common infections worldwide and affect the poorest communities. More than 1.5 billion people, or 24% of the world's population, have soil-transmitted helminth infections (WHO, 2016). The main soil-transmitted helminth species that infect people are roundworms (*Ascaris lumbricoides*) and hookworms (*Necator americanus* and *Ancylostoma duodenale*).

Schistosomiasis, also called bilharzia, is a water-based disease transmitted through urine and caused by a group of helminths called *Schistosoma*. It is common in tropical and sub-tropical areas, affecting almost 240 million people worldwide (WHO, 2014b). According to USAID, “Schistosomiasis is considered second only to malaria as the most devastating parasitic disease in tropical countries (USAID, 2014).”

What is *Ascaris*?

When talking about sanitation, you will often hear about *Ascaris lumbricoides*, a type of roundworm that infects people. *Ascaris* is the most commonly used indicator for whether or not fecal sludge is safe after treatment. *Ascaris* eggs are one of the pathogens most resistant to inactivation in treatment processes and can survive in fecal sludge and soil for months or years. They can also be identified relatively easily in a laboratory (Strande et al., 2014).

Many people around the world are infected with *Ascaris*, especially in tropical and subtropical regions, and in any areas with poor sanitation. Ascariasis is caused by accidentally swallowing eggs found in human and animal feces. This can happen when hands or fingers that have contaminated dirt on them are put in the mouth. Or, if feces with eggs is used to fertilize crops, the eggs may be eaten by people if the food has not been carefully cooked, washed or peeled. Good sanitation and hygiene are key to preventing Ascariasis infections (CDC, 2013).

3.5 Salt

Urine also contains high concentrations of salt. The concentration depends on what a person eats and how much they drink. One study suggested we have on average 8.8 grams of salt per litre of urine (Ganrot, Dave, & Nilsson, 2007). Salt in urine is not a public health issue, but it can be damaging to soils and plants when urine is used as a fertilizer in agriculture.

3.6 Trace Organics

Trace organics such as natural hormones, synthetic hormones and pharmaceuticals can be passed through urine and feces and still be biologically active. Researchers have only recently begun to study whether and how trace organics affect living things in the environment and what this means for public health.

Most trace organics that are excreted by the human body pass through urine. Due to the high prevalence of HIV infections in some countries, high concentrations of pharmaceuticals in urine is expected (Etter, Udert & Gounden, 2015).

3.7 Heavy Metals

Heavy metals are not usually a concern in domestic fecal sludge. These compounds typically come from industrial sources. Some contamination can occur from domestic sources, if for example, batteries are disposed in the latrine. Heavy metals are not removed during fecal sludge treatment, so it is important to avoid contamination in the first place (Strande, Ronteltap & Brdjanovic, 2014).

4 Characterizing and Quantifying Fecal Sludge

It is important to know the characteristics and quantities of fecal sludge to plan and design appropriate management options. The key fecal sludge characteristics include the following:

- **Water content:** The more water there is in fecal sludge, the more volume it takes up and the heavier it is. It is easier to empty watery sludge, but it is more expensive to transport.
- **Solid waste content:** Users often add garbage to their latrine. Various waste products commonly found in latrines include menstrual hygiene products, baby diapers, plastics, textiles, glass, metals, household contaminants, stones, sand and food waste (Strande et al., 2014; Velkushanova, 2015). It should be assumed that fecal sludge will contain at least a small portion of solid waste.
- **Stability of organic material:** Fecal sludge varies from fresh to stabilized (or stable). Fresh sludge has not had time to degrade. Organic material is not broken down. Older sludge has undergone degradation (for example, anaerobic or aerobic digestion) and the organic material is broken down. This process is known as stabilization.

Fecal sludge from one latrine can be very different than sludge from another latrine. The composition of fecal sludge (what's in it) as well as its consistency (how liquid or solid it is) will depend on various factors:

- **Variety of on-site sanitation technologies**: Septic tank, pit latrine, dry latrine
- **Storage duration**: Fecal sludge will be more or less stabilized depending on how long it is stored.
- **Infiltration**: Fecal sludge will be more or less viscous (thick) if there is a high infiltration rate into or out of the containment.
- **Amount of greywater**: Fecal sludge will be more or less dilute depending on the different types of used water going into the on-site sanitation technology (for example, water from bathing, dishwashing, laundry, and cleaning).
- **Emptying method**: Water could be added to help liquefy fecal sludge for pumping. Some emptying methods can only remove part of the contents, for example, fecal sludge at the bottom of a containment technology that is very thick. Other methods can remove the entire contents, for example manual emptying. Sometimes the household can only afford to get part of the contents removed.
- **Climate**: During rainy seasons, on-site sanitation technologies can fill up with runoff and overflow. Warmer temperatures increase degradation rates.
- **Solid waste**: Quantities of solid waste (garbage) disposed in the on-site sanitation technology, depending on access to solid waste management and awareness.

Table: How Fecal Sludge Characteristics Affect Sanitation System Components

Fecal Sludge Characteristic	Sanitation System Component	Common Challenges	Examples
Water content	Emptying	Thick sludge is difficult to empty.	A pump cannot be used to empty a dry latrine pit. Water will need to be added.
	Transport	Watery sludge is heavy and takes up a lot of space.	Wet sludge from a septic tank is easier to pump out with a vacuum truck.
	Treatment	Watery sludge will usually need to be dewatered before focusing on pathogen inactivation.	Sludge from septic tanks will need to be dewatered before composting.
	Use and disposal	Watery sludge has a higher risk of contaminating groundwater if it is to be buried.	Sludge from septic tanks will need to be dewatered before safely burying.
Solid waste content	Emptying and transport	Increases the quantity of sludge.	Owners need to pay higher costs to empty and transport the extra solid waste that is disposed in a pit latrine.
		Solid waste can break emptying technologies and clog pipes and pumps.	Solid waste disposed in a pit latrine will break a motorized pump used to empty the pit contents.
	Treatment	Solid waste can break treatment technologies or stop them from working properly.	Sludge with solid waste should be removed before it is discharged into an anaerobic reactor. The solid waste could damage the reactor and disrupt anaerobic digestion.
	Use and disposal	Solid waste affects the quality of the treated product.	No one will want to use compost that has pieces of garbage in it.
Stability of organic material	Treatment	Fresh sludge contains unstabilized organic material and is difficult to dewater.	Sludge from public toilets will be difficult to dewater as it has not had time to degrade.

Despite its importance, reliable data and accepted methods for characterizing and quantifying and do not yet exist. As well, data from characterization studies also focus on the household level, whereas significant amounts of fecal sludge are generated at public toilets, commercial entities, restaurants and hotels (Strande et al., 2014).

Researchers at Eawag-Sandec are in the process of developing an affordable and simple methodology that can be used to quantify and characterize fecal sludge on a citywide scale, and fill the present knowledge gap. They have hypothesized that demographic data could be used to develop citywide characterization and quantification plans. The methodology is being tested in Kampala, Uganda and Hanoi, Vietnam. More information can be found on the Eawag-Sandec website at: www.eawag.ch/en/department/sandec/projects/ewm/faq-faecal-sludge-quantification-and-characterisation/

Even though it is difficult to characterize and quantify fecal sludge, it shouldn't prevent us from doing the best that we can with the information that we have available. Information on the on-site sanitation technology and how it is operated can indicate some of the sludge characteristics, such as water content. The following sections describe some things that you can do to better understand the characteristics and amounts of fecal sludge that you are dealing with.

4.1 Characterization

The actual latrine itself can provide a lot of information about the fecal sludge characteristics. Key information includes the excreta containment technology, type of user interface, and how long the sludge has been stored. You can better understand the following sludge characteristics by observing the on-site technology and having discussions with the users, emptiers and maintenance staff:

- **Water content:** You can describe how watery the sludge is by understanding the following: type of latrine (for example, wet or dry toilet), excreta storage technology (for example, pit with infiltration to the soil), number of latrine users, amount of water going into system, type of soil, groundwater level, how the sludge is emptied (for example, with or without adding water), and how frequently it is emptied. For example, septic tanks are commonly operated with a greater amount of water and therefore tend to have a greater water content then pit latrines.
- **Solid waste content:** Ask the household if they use the latrine for waste disposal. People may be reluctant to admit what they put in their latrine. A pronged fork can be inserted inside the pit. The volume of solid waste retrieved can give you a better understanding of the quantity and types of solid waste in the fecal sludge.
- **Stability of organic material:** Ask the owner how frequently the latrine is emptied. The storage time will give you a better understanding of the stability of the sludge. For example, the sludge from a public toilet, will tend to be relatively fresh because it requires frequent emptying and was stored for a short period of time.

4.2 Quantification

Quantifying fecal sludge is an approximate science. The following information is needed to estimate the quantity of fecal sludge produced in a community:

- Number of users
- Location
- Types of on-site sanitation technologies
- Number of on-site sanitation technologies
- Fecal sludge accumulation rates

This information is rarely available and time-consuming to collect.

There is currently no proven method to quantify fecal sludge. There are different methods that exist to quantify fecal sludge, but their assessments are based on different factors, resulting in widely variable values.

These methods include determining:

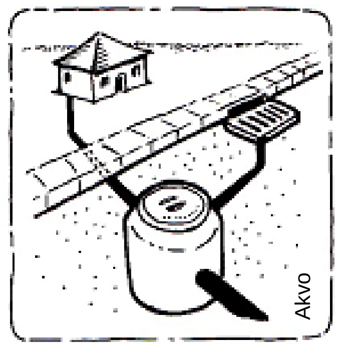
- Fecal sludge accumulation rates in on-site sanitation technologies
- Fecal sludge production based on actual and hypothetical desludging intervals
- Fecal sludge collection rates of service emptying providers

A vacuum truck counting study is an example of determining fecal sludge collection rates. It estimates the amount of fecal sludge currently delivered to a discharge location. In this study, the number of vacuum trucks and their discharge volume is recorded. The study should be implemented over at least one week and should be repeated a few times at different times of the year. This should ensure that the weekly and annual variability of fecal sludge collection is considered. For example, less fecal sludge is commonly discharged on Sundays or during the year when major investments (such as school fees) are due. A vacuum truck counting study does not quantify all of the fecal sludge generated in a community, nor can it predict future developments. As well, it can only be done in cities where fecal sludge discharge locations exist.

5 What is Wastewater?

Wastewater (also called sewage) is a combination of excreta and toilet flush water that is transported directly from the home through a system of pipes (called sewers) to a wastewater treatment facility. Sometimes the wastewater is discharged without treatment. Wastewater may also contain used water from other household activities (also known as greywater).

People often confuse fecal sludge and wastewater. Fecal sludge comes from an on-site sanitation technology, whereas wastewater is transported through a sewered system.



Conventional sewered system

There are also differences between the characteristics of fecal sludge and wastewater. The two main differences are the following:

1. **Variability:** Fecal sludge is highly variable in consistency, concentration and quantity because it comes from different types of on-site sanitation technologies, different uses, different households, and different management styles. Wastewater is more homogenous and consistent because it is mixed as it is transported through the sewers. It is therefore easier to manage because its characteristics are more predictable and we can make generalizations about the averages.
2. **Stability:** Wastewater is transported directly from the home to the wastewater treatment facility through a sewered system. Whereas fecal sludge is stored for a certain period of time in a containment technology (like a latrine pit or septic tank). Depending on the length of storage, fecal sludge can be more degraded and stabilized than wastewater.

Wastewater treatment technologies are not appropriate for fecal sludge treatment. Using a wastewater treatment technology to treat fecal sludge always results in failure (Strande et al., 2014). It is a common misconception that all wastewater technologies can be simply transferred to fecal sludge.

6 Glossary

Characterization: Describing the biological, chemical, and physical properties of fecal sludge.

Excreta: Urine and feces not mixed with any flush water.

Fecal bacteria: Bacteria found in the feces of humans or warm-blooded animals.

Fecal sludge: Also called sludge. Excreta from an on-site sanitation technology (like a pit latrine or septic tank) that may also contain used water, anal cleansing materials, and solid waste.

Greywater: Used water from household activities, such as laundry, dishwashing, bathing, and cleaning. It does not include toilet flush water.

Helminth: Also called worm or fluke. Large, multicellular organisms that are generally visible to the naked eye in their adult stages. Helminths can be either free-living or parasitic in nature. In their adult form, helminths cannot multiply in humans.

Latrine: Also called an on-site sanitation technology. A latrine is made up of all the parts included in the first two boxes of a sanitation system: user interface and excreta storage. Latrine parts include the superstructure, toilet, slab, and the pit, tank or chamber to contain excreta. It may also include accessories such as handrails and a handwashing station.

Nutrient: Any substance that is used for growth. Nitrogen (N), phosphorus (P), and potassium (K) are the main nutrients in agricultural fertilizers.

On-site sanitation technology: Also known as a latrine. An on-site sanitation technology is made up of the parts included in the first two components of a sanitation system: user interface and excreta storage. Excreta is collected and stored where it is produced (for example, a pit latrine, septic tank, aqua privy, and non-sewered public toilets). Often, the fecal sludge has to be transported off-site for treatment, use or disposal.

Organic material: Also called organic matter. Comes from the remains of living things, such as plants and animals.

Parasite: An organism that lives on or in a host organism and gets its food from or at the expense of its host.

Pathogen: An organism that causes disease.

Protozoa: Microscopic, one-celled organisms that can be free-living or parasitic in nature. They are able to multiply in humans, which contributes to their survival and also permits serious infections to develop from just a single organism.

Quantification: Describing the quantity of fecal sludge produced.

Sewered system: Also called a sewer system, sewerage system, sewers, connected sanitation, and networked sanitation. A sanitation system that transports wastewater through a pipe network (like a simplified sewer, solids free sewer or conventional sewer) to another location for treatment, use or discharge. This includes centralized systems and decentralized wastewater treatment systems.

Stabilization: Degradation of organic material with the goal of reducing readily biodegradable compounds to lessen environmental impacts (such as oxygen depletion and nutrient leaching).

Treatment: Any process to inactivate pathogens, stabilize, dewater, or manage nutrients in fecal sludge.

Wastewater: Used water from any combination of domestic, industrial, commercial or agricultural activities, surface runoff (stormwater), and any sewer inflow (infiltration). Wastewater can be managed on-site or off-site. Wastewater managed off-site is often called sewage.

7 Additional Resources

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- This is the first book dedicated to faecal sludge management. It summarizes the most recent research in this rapidly evolving field, and focuses on technology, management and planning. It addresses faecal sludge collection and transport, treatment, and the final end use. The book also goes into detail on operational, institutional and financial aspects, and gives guidance on integrated planning involving all stakeholders. It is freely available online in English and Spanish, and is coming out in French in 2017.

Sustainable Sanitation Alliance (SuSanA). Available at: www.susana.org

- SuSanA is an open international network of members who share a common vision on sustainable sanitation. SuSanA works as a coordination platform, working platform, sounding board, contributor to the policy dialogue on sustainable sanitation, and as a catalyst. The SuSanA website provides extensive resources including publications, case studies, photos and videos and a discussion forum targeted at practitioners, educators and researchers.

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CAWST (Centre for Affordable Water and Sanitation Technology)
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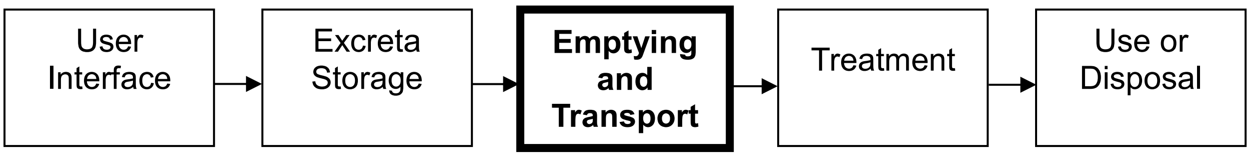
Website: www.cawst.org Email: support@cawst.org
Wellness through Water.... Empowering People Globally
Last Update: July 2016

Centre for Affordable Water and Sanitation Technology

Technical Brief: Sanitation System – Emptying and Transporting Fecal Sludge

Sanitation System



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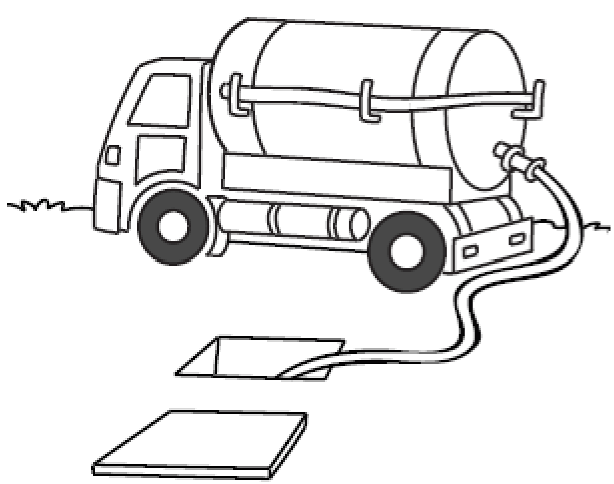


Technical Brief: Sanitation System – Emptying and Transporting Fecal Sludge

1 Introduction

A sanitation system deals with human excreta from the time it is generated until it is used or disposed of safely. The third component of a sanitation system addresses safely emptying fecal sludge from on-site sanitation technologies, and then transporting the sludge for treatment, use or disposal.

Emptying (also called collection) and transporting fecal sludge is a critical link in a sanitation system. Great efforts are being made globally to reduce open defecation by building on-site sanitation technologies, like pit latrines and septic tanks. However, it is not enough to only build an on-site technology to ensure good sanitation and protect public health. The technologies will eventually fill up with fecal sludge. Yet, emptying full technologies and safely managing the fecal sludge is an essential service that is often neglected. 2.7 billion people around the world use on-site sanitation technologies that need fecal sludge management services (Strande, Ronteltap & Brdjanovic, 2014).

Some on-site sanitation technologies, like septic tanks and aqua privies, are designed to be emptied periodically. For other technologies, like pit latrines, people need to decide whether to empty the pit or dig a new one. Emptying is a common practice in densely populated areas where households are not connected to a sewered system or do not have the space to dig a new latrine pit when the old one is full.

On-site sanitation technologies, like a pit latrine, will eventually fill up with fecal sludge

Ideally, well-equipped and protected service providers should empty on-site sanitation technologies and transport the sludge to a treatment, use or disposal site. However, in reality, many on-site technologies are either abandoned or emptied using unsafe and unhygienic methods. Fecal sludge is simply dumped by the home, in the street, or in nearby water sources.

Emptying and transporting fecal sludge can be made more efficient and safe for sanitation service providers, households, communities, and the environment. This Technical Brief introduces the health and safety concerns, and different methods to efficiently and safely empty and transport sludge from on-site sanitation technologies.

> CAWST focuses on the planning, design, and implementation of on-site sanitation projects for low-income communities not connected to a sewer. For such communities, household or decentralized sanitation offers a hygienic and affordable solution.
>
> CAWST's free, open content resources and schedule of international training workshops can be found at: https://resources.cawst.org and www.cawst.org/training.

Technical Brief: Sanitation System – Emptying and Transporting Fecal Sludge

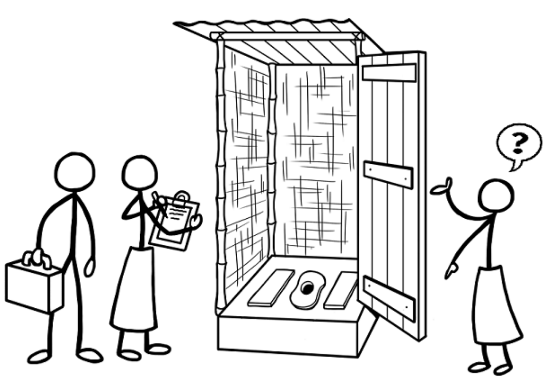
2 Service Provision

There are a range of service providers for fecal sludge emptying and transport, from informal and independent individuals to formal and large companies. In some areas, services are also provided by public utilities or nongovernmental organizations (Chowdhry & Kone, 2012). It is common to see a variety of service providers working in the same region due. This is because of the complexity and accessibility of different on-site sanitation technologies and the customers' ability to pay for the services (Strande, Ronteltap & Brdjanovic, 2014).

Regardless of who provides the service, they should perform the following tasks when visiting a household (Strande, Ronteltap & Brdjanovic, 2014):

1. Go to the household and bring the required equipment.
2. Meet the customer to arrange logistics and inform them of the service.
3. Tell them the fee or negotiate with the customer, depending on the business model.
4. Put on personal protective equipment (like gloves, boots, masks, and protective clothing).
5. Locate the on-site sanitation technology.
6. Determine the access point of the on-site sanitation technology.
7. Open the on-site sanitation technology cover.
8. Remove solid waste, if necessary.
9. Empty the on-site sanitation technology.
10. Evaluate the condition of the on-site sanitation technology.
11. Close and secure the on-site sanitation technology.
12. Clean the areas around the on-site sanitation technology.
13. Do a final inspection and report any issues to the customer.
14. Transport the fecal sludge to a treatment or disposal facility.

As well, service providers can provide valuable information to their customers and answer any questions. Local governments should work with service providers to distribute information about their on-site sanitation technology, the importance of fecal sludge management, and good hygiene practices. Service providers can hand out, for example, pamphlets on the importance of maintaining and emptying on-site sanitation technologies.



3 Emptying Technologies

There are two ways to empty sludge from an on-site sanitation technology:

1. Manual emptying (using a bucket or hand pump)
2. Mechanized emptying (using a mechanized pump or vacuum truck)

The advantages and limitations of each method are summarized in the following table and described in the next sections.

Table: Advantages and Limitations of Manual and Mechanized Emptying

Method	Advantages	Limitations
Manual emptying	• Potential for local job and income generation • Simple hand pumps can be built and repaired with locally available materials • Low capital costs • Provides service to difficult to access on-site sanitation technologies • More affordable service for the poor	• Hard and unpleasant work • Increased health risks to emptiers from exposure to fecal sludge • Increased safety risks to emptiers from entering pits and tanks • Increased public health and environmental risk from spilt fecal sludge • Time consuming, can take several days depending on the size of the technology • Bad smells
Mechanized emptying	• Potential for local job and income generation • Fast and generally effective fecal sludge removal • Reduced health, safety and environmental risks	• High capital, operating and maintenance costs • Not all parts and materials many be locally available • Not all households may be able to afford the service • May have difficulties to access on-site sanitation technologies (for example, narrow roads) • Cannot pump thick sludge (must be thinned with water or manually removed) • Pumps can usually only suck down to a depth of 2–3 metres, cannot completely empty deep technologies • Pump must be located within 25 metres of the technology

(Adapted from Strande, Ronteltap & Brdjanovic, 2014; Tilley, Ulrich, Luthi, Reymond & Zurbrugg, 2014; WaterAid, 2013)

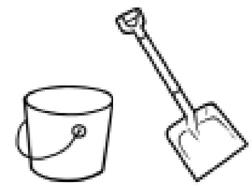
Whether on-site sanitation technologies are emptied manually or with mechanized equipment, owners can make it safer to empty in the following ways:

- Fully lining latrine pits to prevent the walls from collapsing when emptied. See CAWST's latrine design and construction materials for more information on pit lining.
- Building two (twin) latrine pits, so the contents of one pit are left to degrade while the other pit is being used. This makes the fecal sludge safer to handle when it is time to empty the pit.

- Not disposing solid waste into the latrine. Fecal sludge mixed with garbage can be impossible to empty using motorized equipment. Garbage such as glass, medical waste or sharp objects are significant health and safety risks to the people emptying the on-site sanitation technologies and treating the sludge.

3.1 Manual Emptying

Manual emptying is typically done in low-income areas and informal settlements that are inaccessible by mechanical equipment and trucks. A recent survey of 30 cities in Africa and Asia found that about one-third of households manually empty their on-site sanitation technologies. While family members sometimes do this job themselves, a manual emptier is hired almost 90% of the time (Chowdhry & Kone, 2012).



As well, some on-site sanitation technologies can only be emptied manually. For example, composting latrines and dehydrating latrines must be emptied with a shovel. This is because the material is solid and cannot be removed with a vacuum or a pump.

There is a social stigma attached to manual emptying. People willing to do this kind of work are often the poor and disadvantaged in need of additional income. Manual emptying is hard and unpleasant work, and it poses serious health and safety risks if it is not carefully managed. The tools used for manual emptying are simple, usually no more than a bucket, shovel, and rope. Workers often use minimal or no personal protection, like gloves or boots, to prevent direct contact with the fecal sludge. As a result, they report injuries, skin rashes, and other diseases (Chowdhry & Kone, 2012; Opel, 2012).

Workers (or the householders doing the work) need to understand the risks of emptying on-site sanitation technologies and handling fecal sludge. They must know to take health and safety precautions, such as:

1. Wear gloves, boots, protective clothing, and masks while emptying the pit. Wash hands and body with soap afterwards.
2. At least part of the slab or cover will have to be removed to allow access and improve air circulation. The on-site sanitation technology should be allowed to vent for a while before anyone begins work. Venting lets harmful gases (like methane, ammonia, and sulphur dioxide) escape and fresh air to enter.
3. No one should enter a pit without a harness and safety rope. There should be two people holding the rope who can pull the worker out if they are overcome by gases or if the pit walls collapse.

Some portable, manually operated pumps have been developed to improve the efficiency of manual emptying and better protect the health and safety of workers. Some of these technologies include the:

- Manual diaphragm pump: Workers push and pull the handle of the hand pump. The fecal sludge is pumped up through the main shaft and discharged through a spout.

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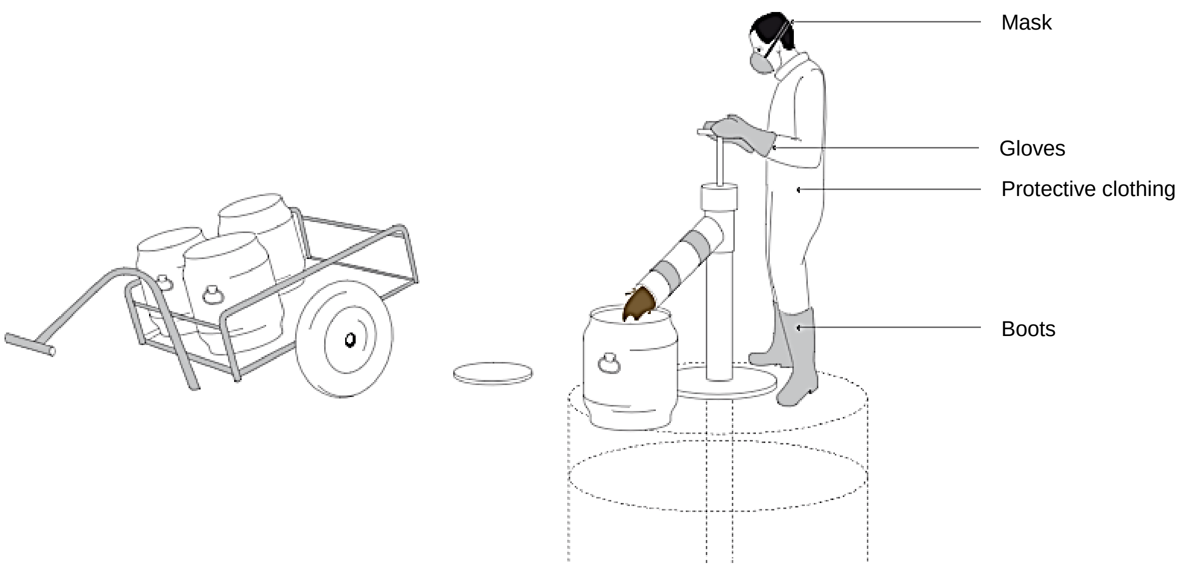
- Manual pit emptying technology (MAPET): The hand pump is connected to a vacuum tank mounted on a pushcart. When the hand pump is turned, air is sucked out of the vacuum tank and sludge is sucked up into the tank.
- Gulper: Works on the same concept as a water pump. When the handle is pumped, the sludge rises up through the bottom of the pump and is forced out of a spout.



Using a manually operated pump (Credit: Tilley et al., 2014)

Manual emptying technologies have experienced various technical and implementation challenges. For instance, some pumps clog with sludge that contains household solid waste, which is commonly found in pit latrines. As well, some are not designed with locally available pumps or spare parts, and rely on importation.

Of all the manual emptying technologies, the Gulper has reached the widest number of pit emptying service providers in Asia and Africa. This is mainly due to strong interventions from external organizations, like nongovernmental organizations (NGOs), that provided funding, training and technical support (Strande, Ronteltap & Brdjanovic, 2014).

Design Tip

Manually emptying sludge (with buckets and a shovel) from pits deeper than 1.5 metres is impossible, unless the emptier climbs inside the pit, which is a serious health and safety risk. A compromise must be made between the pit depth and the frequency and difficulty of emptying. Shallow pits (less than 1.5 metres deep) are easier to empty and have less health risks to emptiers than deeper pits, but they need to be emptied more often.

(Buckley et al., 2008; Still & Foxon, 2012; Tilley et al., 2014)

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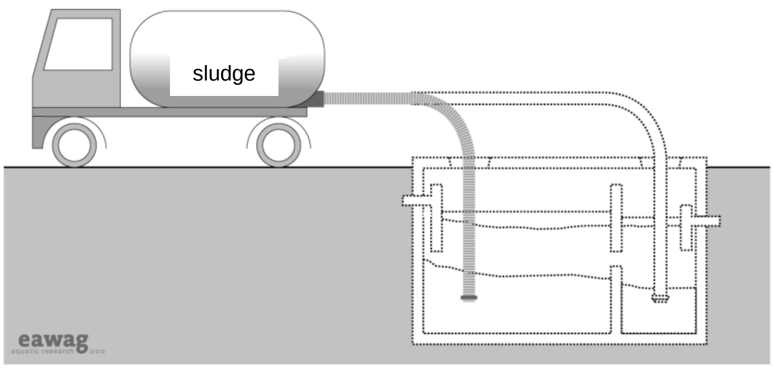
3.2 Mechanized Emptying

Mechanized fecal sludge emptying technologies are powered by electricity, fuel or pneumatic systems (using pressurized air or gas).

Vacuum pumps are effective in emptying water-based on-site sanitation technologies, like pour flush latrines, septic tanks, and aqua privies. The pump is connected to a hose that is lowered through an access cover into the technology. The fecal sludge is then pumped into the storage tank mounted on a heavy duty truck or trailer, on lighter carts, or even human powered carts for smaller volumes (Strande, Ronteltap & Brdjanovic, 2014).

Vacuum trucks are available in a wide variety of sizes and models to meet different needs. Most commonly they have a storage capacity of 200 to 16,000 litres. Conventional vacuum trucks can hold as much as 55,000 litres (Strande, Ronteltap & Brdjanovic, 2014).



Emptying a septic tank with a vacuum truck (Credit: Tilley et al., 2014)

Mechanized emptying can be a fast and efficient way to empty on-site sanitation technologies, especially large tanks. It is also much safer and healthier for the service providers compared to manual emptying methods. Service providers need to operate the pump and move the hose, but they do not need to enter the technology or have direct contact with the fecal sludge.

However, there are some technical limitations for using vacuum trucks. Conventional vacuum trucks can usually only suck down to a depth of 2 to 3 metres. They also must be parked within 25 metres of the on-site sanitation technology, depending on the strength of the pump (Strande, Ronteltap & Brdjanovic, 2014). As well, large vehicles are often unable to access narrow streets and poor roads, especially in unplanned and informal communities.

Vacuum trucks are also designed for emptying water-based technologies, such as pour flush latrines, septic tanks, and aqua privies. Depending on the technology, the sludge can become too thick and cannot easily be pumped. In this case, it is necessary to dilute the fecal sludge with water so that it can flow more easily. However, this is inefficient and potentially costly. If water is not available, then manual emptying may be the only option to empty the technology (Tilley et al., 2014).

Other challenges of using conventional vacuum trucks include:

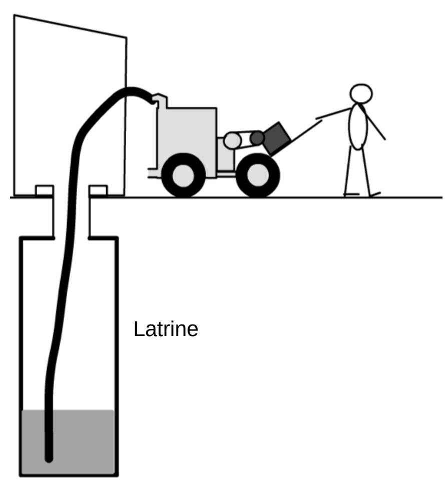
- Most are manufactured in North America or Europe, so they are expensive to import and buy locally.
- It is difficult to locate spare parts and a local mechanic to repair broken pumps and trucks.
- Poor households often cannot afford the services.

Smaller, mobile, and inexpensive pumps and vehicles have been developed to help overcome the challenges of using a large vacuum truck. However, none these technologies are yet used at scale.

For example, UN-HABITAT started the Vacutug project in 1995. It requested a design for a motorized system that could be:

- Manufactured locally
- Affordable
- Easily serviceable
- Able to operate in narrow streets
- Capable of pumping out dense sludge from on-site sanitation technologies

At the same time, sludge must be emptied as safely as possible without causing further health issues to the workers and the community. It has been tested by the UN and various nongovernmental organizations (NGOs) in some African and Asian countries; however, large-scale production and distribution of the Vacutug on a global scale has yet to start (UN-HABITAT, n.d.).



Small portable pump for pit emptying
(Credit: UN-Habitat, n.d.)

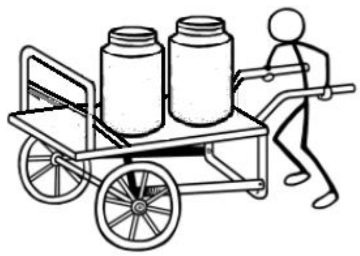
4 Transportation Methods

A safe method for transporting the fecal sludge must also be arranged. Similar to emptying, transport technologies can be classified into two categories:

1. Manual using human or animal power
2. Motorized using a fuel-powered engine

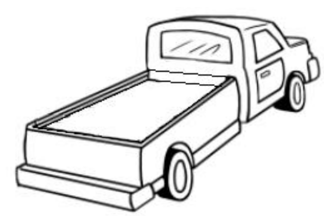
Manual service providers generally use simple, low-cost transportation methods that rely on human or animal power, such as a:

- Cart
- Wheelbarrow
- Wagon
- Rickshaw



Manual service providers often use open containers to transport the fecal sludge. The sludge should be put into covered containers with tightly fitting lids to reduce the risk of spills when it is transported.

Containers of sludge with capacities of up to 200 litres can be transported using manual push or pull carts. The carts are designed to fit into tight spaces and can transport fecal sludge about 500 metres, and sometimes up to three kilometres (Strande, Ronteltap & Brdjanovic, 2014).



Larger-scale manual emptying operations may be able to afford a small pick-up truck or other motorized vehicle to transport fecal sludge a further distance away. Motorized tricycles are the smallest type of low-cost motorized vehicle used to move sludge. They vary in size and power, and are able to access narrower streets than larger trucks. Some tricycles can carry up to 1,000 kg of sludge; whereas pick-up trucks can transport between 2,000 to 5,000 kg at one time (Strande, Ronteltap & Brdjanovic, 2014).

Both manual and motorized transportation methods face various challenges related to the following:

- **Road width and slope**: In densely populated areas roads can be narrow. Certain vehicles are not able to access the roads to service households. Steep slopes also reduce the accessibility of households.
- **Poor road construction**: It is difficult and dangerous for certain vehicles to use roads that are not maintained. Holes in the road, for example, could tip over a cart or pick-up truck. Pedestrians could be hurt and fecal sludge could spill onto the streets.
- **Accessibility in rainy season**: Roads can flood during a rainy season. Vehicles may not be able to pass through the flooded roads.

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- **Traffic**: In urban areas, traffic is often dense and dangerous. Larger vehicles are more likely to get stuck in traffic. Smaller vehicles need to be particularly attentive to other vehicles.
- **Breakdown and repair**: Vehicles often breakdown and need to be repaired. The skills, tools, and spare parts to repair a vehicle are often not available or are expensive.
- **The weight of fecal sludge**: Fecal sludge is heavy, which limits how much sludge can be carried. It also makes it expensive to transport sludge over a long distance.
- **Risk of theft, damage and abuse**: This risk applies to all vehicles, including vehicles transporting sludge.

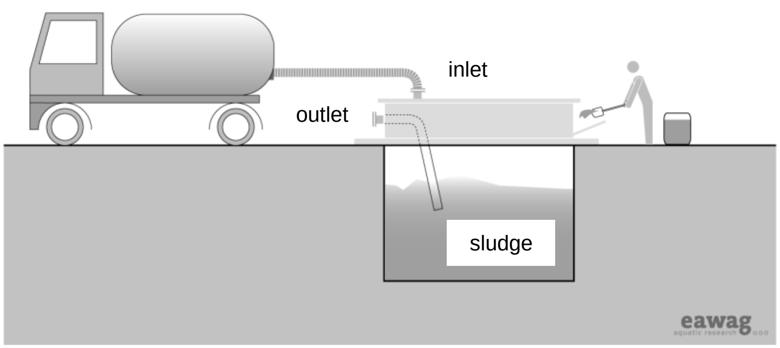
Vacuum trucks or other large vehicles with storage tanks are generally able to transport sludge directly to the treatment, use or disposal facility. However, due to the challenges for manual service providers to transport sludge, a common practice is to dump or bury the fecal sludge near the home, or dispose it in the local sewer system. However, moving the sludge just a few metres away from where it was collected does not provide a sustainable or hygienic solution for sludge disposal.

What About Disposing Fecal Sludge in the Sewer System?

Fecal sludge should not be disposed of in the sewer system. Yet, illegally dumping fecal sludge into the sewer system is common in low-income countries because it's easy to access and there are usually no other disposal options. Fecal sludge has a higher solids content than wastewater and it can clog the sewers. As well, it can lead to severe disruptions of the wastewater treatment facility. This is because fecal sludge has different characteristics than wastewater. See CAWST's Technical Brief: What is Fecal Sludge for more information on the differences between fecal sludge and wastewater.

(Strande, Ronteltap & Brdjanovic, 2014)

Transfer stations are an option when fecal sludge cannot be easily transported over a long distance. Transfer stations are fixed (permanent) or mobile (temporary) places to dispose of and store sludge. When the transfer station is full, a vacuum truck empties the sludge and takes it to a treatment or disposal facility. Easy and affordable access to a transfer station may help to reduce the incidence of illegal sludge dumping and encourage households to empty their on-site sanitation technologies more regularly. Transfer stations are still in the stage of innovative technology without actual field experience in developing countries other than a few pilot projects.

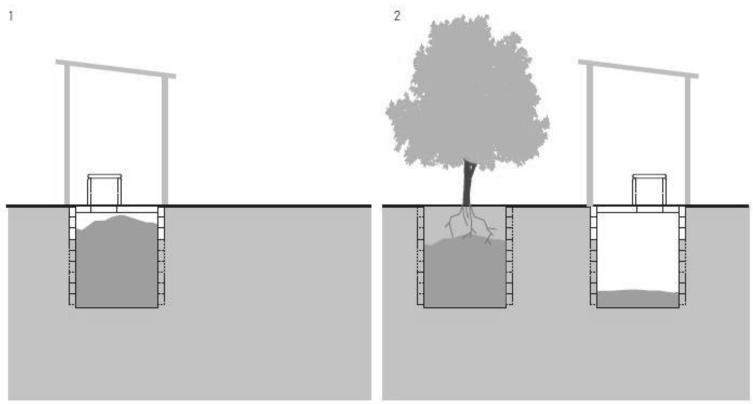


Manual service providers can dispose of fecal sludge in a local transfer station (Credit: Tilley et al., 2008)

5 Relocating Latrines

Some on-site sanitation technologies, like pit latrines and ventilated improved pit (VIP) latrines, can be relocated when the pit is full. To decommission or close a pit, it can simply be filled with soil and covered. The full, covered pit poses no immediate health risk, and the fecal sludge will degrade naturally over time (Tilley et al., 2014).

Other latrines are specifically designed to be relocated when the pit is full. For example, the Arborloo latrine uses a shallow pit for storing fecal sludge that is filled and covered with soil when the pit is full. A tree is then planted on top of the filled pit which can grow well in the nutrient-rich soil. The superstructure, slab and footing are portable and are moved to a new pit. For more information, see the CAWST's Sanitation Fact Sheet: Arborloo Latrine.



Arborloo latrine (Credit: Tilley et al., 2014)

Households need to decide whether to empty the latrine pit to reuse it or dig a new one. Filling and covering pits is an adequate solution when emptying is not possible and when there is space to continuously re-dig and fill pits. Latrine emptying is a common practice in peri-urban and urban communities where households do not have sewered systems or the space to dig a new pit when the old one is full.

Table: Advantages and Limitations of Latrine Relocation

Advantages	Limitations
• Less expensive than paying for emptying services • Low risk of pathogen transmission since households do not come in contact with the fecal sludge • For Arborloo latrines, planting a tree can reforest an area, provide a sustainable source of food, and prevent people from falling into old latrine pits	• Needs space to regularly dig a new pit • Time consuming • Labour intensive • May not be socially acceptable to use fecal sludge to grow trees or food depending on the local culture

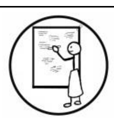
6 Risk Management

Fecal sludge must be emptied and transported in a way that protects service providers, households, communities, and the environment. Fecal sludge is a major source of pathogens, such as bacteria, viruses, protozoa and helminths that cause disease. As well, emptying fecal sludge can also pose safety risks, such as:

- Workers being buried by walls collapsing in unlined latrine pits
- Injury from garbage disposed in the on-site sanitation technology
- Workers breathing in harmful gases in the on-site sanitation technology

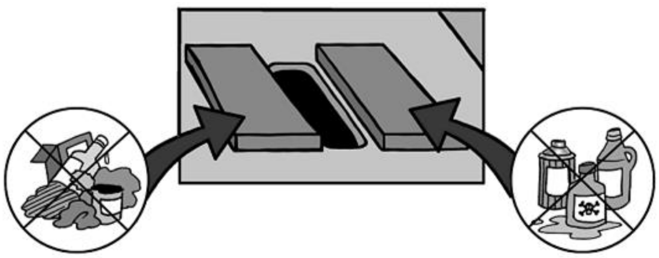
There are many protective measures (also called barriers) that should be put in place when emptying and transporting fecal sludge. This is often known as a multi-barrier approach. The following table shows barriers that can be used to avoid the spread of pathogens and protect public health.

Table: Protective Measures for Emptying and Transporting Sludge

Barriers to Protect Health		Action
	Use protective equipment	Wear protective equipment, such as clothing, gloves, boots, and mask. Clean and disinfect the equipment used.
	Wash hands	Wash hands with soap after handling fecal sludge, tools, and equipment.
	Clean tools	Disinfect the tools used for emptying and transport, and only use them for this activity. Safely store the tools so people do not touch them or use them for another purpose.
	Use containers with lids	Use an undamaged container with a tight fitting lid to prevent fecal sludge from spilling during transportation.
	Keep site clean	Clean the area where fecal sludge may have spilled.
	Train	Train service providers on proper emptying and transport procedures and hygiene practices. Train local community on the importance of regular emptying and the importance of not putting solid waste into the latrine.
	Deworm	Provide treatment for helminth infection to service providers and their families to stop the cycle of transmission and reduce helminths in fecal sludge.

Latrines Used as Garbage Dumps

Research on VIP latrine use in South Africa has shown that people often dispose of garbage into their pits when there is no proper solid waste management system. Solid waste may include menstrual hygiene products, condoms, health care waste (such as used needles), paper, metal, glass and organic material (such as kitchen and garden waste). (Buckley et al., 2008; Still and Foxon, 2012). Solid waste often needs to be “fished” out of the latrine before it can be emptied. This is time-consuming and a very messy job.



Alternative latrine technologies that make sludge easier to empty and safer to handle can also be used. Examples include twin pit latrines or latrines with aboveground chambers that have an access door to remove sludge. Twin pit latrines use two alternating pits; one pit is used for two years (or longer) and then covered while the other is used. Generally, after a two-year storage period the pathogens have been reduced and the fecal sludge is safer to handle. Pit latrines and VIP latrines can be constructed with twin pits. Building two pits, however, requires extra land space and for households to make a greater financial investment.

See CAWST’s Sanitation Fact Sheets and Latrine Construction Manual for more information about the design and safety of different technologies.

7 Definitions

Characterization: Describing the biological, chemical, and physical properties of fecal sludge.

Excreta: Urine and feces that are not mixed with any flush water.

Fecal sludge: Also called sludge. Excreta from an on-site sanitation technology (like a pit latrine or septic tank) that may also contain used water, anal cleansing materials, and solid waste.

Fecal sludge management: Includes the emptying, transport, treatment, and safe use or disposal of fecal sludge from an on-site sanitation technology (like a pit latrine or septic tank). Some people also include storage in the definition of fecal sludge management.

Informal settlements: Unplanned residential areas that have been constructed where residents do not own the land, and housing is not in compliance with planning or building regulations.

Technical Brief: Sanitation System – Emptying and Transporting Fecal Sludge

Non-sewered system: Also called on-plot or on-site sanitation. A sanitation system in which excreta and used water are collected and stored on the location where it is produced. Often, the fecal sludge has to be transported off-site for treatment, use or disposal.

On-site sanitation technology: Also known as a latrine. An on-site sanitation technology is made up of the parts included in the first two components of a sanitation system: user interface and excreta storage. Excreta is collected and stored where it is produced (for example, a pit latrine, septic tank, aqua privy, and non-sewered public toilets). Often, the fecal sludge has to be transported off-site for treatment, use or disposal.

Sewered system: Also called a sewer system, sewerage system, sewers, connected sanitation, and networked sanitation. A sanitation system that transports wastewater through a pipe network (like a simplified sewer, solids free sewer or conventional sewer) to another location for treatment, use or discharge. This includes centralized systems and decentralized wastewater treatment systems.

Treatment: Any process to inactivate pathogens, stabilize, dewater, or manage nutrients in fecal sludge.

8 Additional Resources

CAWST Sanitation Resources. Available at: https://resources.cawst.org/

- CAWST's education and training resources are available on a variety of sanitation topics including environmental sanitation; latrine design, siting and construction; fecal sludge management; and sanitation project implementation.

Faecal Sludge Management: Systems Approach for Implementation and Operation. Strande, L., Ronteltap, M. & Brdjanovic, D. (2014). London, UK: IWA Publishing. Available at: www.sandec.ch/fsm_book

- This is the first book dedicated to faecal sludge management. It summarizes the most recent research in this rapidly evolving field, and focuses on technology, management and planning. It addresses faecal sludge collection and transport, treatment, and the final end use. The book also goes into detail on operational, institutional and financial aspects, and gives guidance on integrated planning involving all stakeholders. It is freely available online in English and Spanish, and is coming out in French in 2017.

Compendium of Sanitation Systems and Technologies. Tilley, E., Ulrich, L., Lüthi, C., Reymond, P. & C. Zurbrügg (2014). 2nd Revised Edition. Eawag: Swiss Federal Institute of Aquatic Science and Technology, Dübendorf, Switzerland. Available at: www.eawag.ch/forschung/sandec/publikationen/compendium_e/index_EN

- The Compendium presents the concept of sanitation systems together with detailed information about sanitation technologies for each component of sanitation systems. The document targets engineers, planners and other professionals who are familiar with sanitation technologies and processes. However, it is also a useful document for non-experts to learn about the main advantages and limitations of different technologies and the appropriateness of different systems.
- The e-Compendium, is an online, interactive version of the Compendium, complete with a tool for combining technologies into a complete sanitation system. Available at: http://ecompendium.sswm.info/

Investigation into Methods of Pit Latrine Emptying. O'Riordan, M. (2009). Management of Sludge Accumulation in VIP Latrines. WRC Project 1745. Pretoria, South Africa: Water Research Commission. Available at: www.susana.org/en/resources/library/details/1424

- Includes an overview of several manual and mechanized pit emptying technologies.

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Wellness through Water.... Empowering People Globally
Last Update: July 2016

Technical Brief: Fecal Sludge Treatment – Pathogen Inactivation Mechanisms

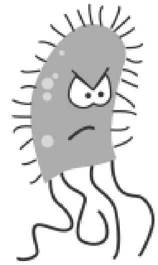
Sanitation System

User Interface → Excreta Storage → Emptying and Transport → **Treatment** → Use or Disposal

Contents

Technical Brief: Fecal Sludge Treatment – Pathogen Inactivation Mechanisms

1 Introduction



Fecal sludge naturally contains many living things. Some are harmless or even beneficial, but others can cause illness. Living things that cause disease are also known as **pathogens**. They are sometimes called other names, such as organisms, microorganisms, microbes or bugs, depending on the local language and country. There are four different categories of pathogens: bacteria, protozoa, viruses, and helminths (worms).

Pathogens can be inactivated (also called reduced) in fecal sludge using different physical, chemical, and biological treatment mechanisms. These include time, temperature, moisture, pH, and solar radiation. This Technical Brief explains how these different ways (also called mechanisms) inactivate pathogens.

Knowing the different ways that pathogens can be killed is helpful to understand how treatment technologies work. As well, understanding pathogen inactivation helps to monitor the safety of treated fecal sludge.

For more information on the different treatment technologies, see CAWST's Technical Brief: Sanitation System – Fecal Sludge Treatment and CAWST Eawag-Sandec Treatment Technology Fact Sheets.

CAWST focuses on the planning, design, and implementation of on-site sanitation projects for low-income communities not connected to a sewer. For such communities, household or decentralized sanitation offers a hygienic and affordable solution.

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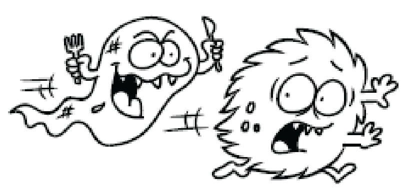
2 Time

The number of pathogens in fecal sludge will decrease over time. Inside the human body, pathogens enjoy optimal conditions to survive and multiply. However, once they are excreted from our bodies, the conditions are not as good. For example, the temperature changes, food might not be as available, and they may have predators. Pathogens in fecal sludge will be eaten by other microorganisms, starve, or naturally die-off over time.



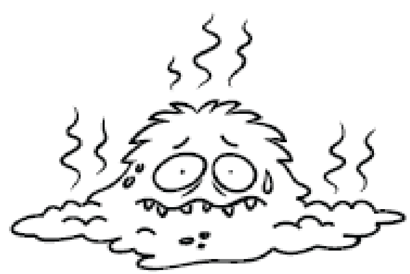
Technical Brief: Fecal Sludge Treatment – Pathogen Inactivation Mechanisms

Sometimes the environmental conditions are favourable for the pathogens to survive. In certain conditions, pathogens can survive for a long time and some can even reproduce. Some pathogens, like *Ascaris lumbricoides* (roundworm) eggs, can remain viable for years because of their impermeable eggshell (Strande, Ronteltap & Brdjanovic, 2014). Protozoa and viruses can only multiply when they are in a host, like a person or animal.

Many fecal sludge treatment technologies inactive pathogens over time. For more information about these technologies see CAWST and Eawag-Sandec's Treatment Technology Fact Sheets:

- Anaerobic digestion
- Black soldier fly larvae
- Co-composting
- Planted drying bed
- Settling-thickening
- Storage
- Thermal drying
- Deep row entrenchment
- Fish pond
- Plant pond
- Unplanted drying bed
- Vermicomposting
- Vermifilter

3 Temperature



Raised temperatures can kill pathogens. Pathogens have optimal growth temperatures. If it is too hot or too cold, they slow down their activity to survive for a longer time. However, over certain temperatures, molecules that are essential for life are denatured. This means that the structure of the molecule is changed. Denaturation is similar to the physical change in proteins you see when you fry an egg.

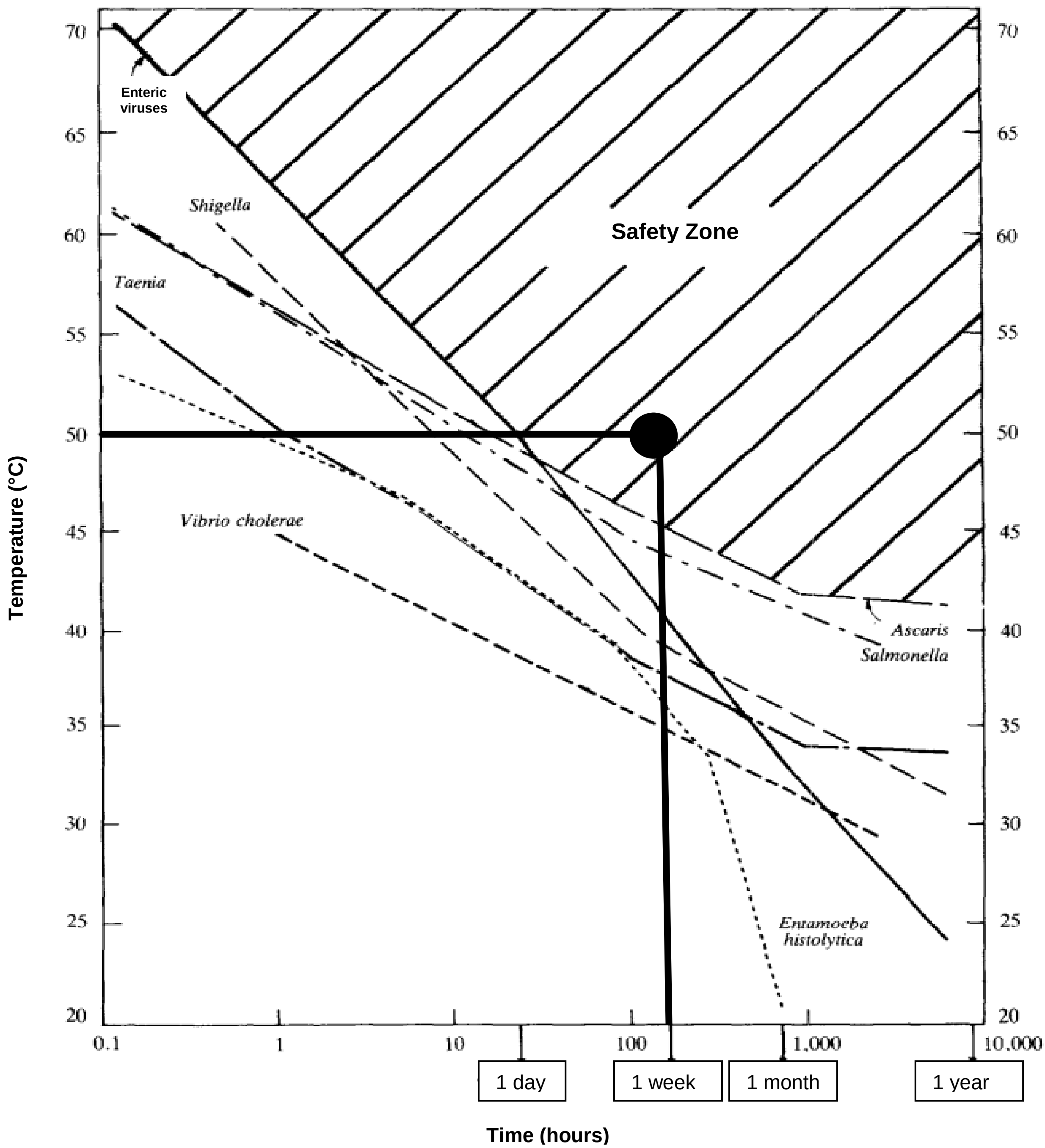
For composting, fecal sludge should be kept at temperatures above 50°C for at least one week, to ensure that pathogens are killed to a safe level (WHO, 2006). Most pathogens in fecal sludge will die in less than a day at temperatures between 40-50°C (Feachem, Bradley, Garelick & Mara, 1983). For example, enteric viruses will die at 50°C after one day. The bacteria *Vibrio cholerae* will die at 38°C after one day.

The graph below shows how long it takes to kill pathogens at different temperatures. There are various ways to read this graph:

- You can look at a specific pathogen and read the temperature and time required to inactivate it.
- You can look at a specific temperature and time and read what pathogens are inactivated and which ones remain alive.

Technical Brief: Fecal Sludge Treatment – Pathogen Inactivation Mechanisms

Figure: Pathogen Inactivation in Relation to Temperature and Time



(Feachem et al., 1983)

Technical Brief: Fecal Sludge Treatment – Pathogen Inactivation Mechanisms

It is important to note that high temperatures are difficult to reach naturally, even in hot climates. The temperature of fecal sludge in a pit latrine, for example, is similar to the temperature outside. This means that households and communities need to reach these temperatures using treatment technologies, or design their on-site sanitation technologies to store the sludge for a long time to reduce pathogens. The following table lists the World Health Organization (WHO) recommendations for temperatures and timeframes needed to reduce pathogens.

Table: WHO Temperature and Time Treatment Recommendations

Temperature	Timeframe	Pathogen Reduction
2-20°C	1.5-2 years	• Will eliminate bacteria, although some might be dormant and could be reactivated • Will reduce viruses and protozoa below risk levels • Some helminth eggs may persist
20-35°C	At least 1 year	• Substantial to complete inactivation of viruses, bacteria, and protozoa • Inactivation of helminth eggs within a few months, apart from *Ascaris* eggs that can take longer

(WHO, 2006)

Co-composting is the most commonly used fecal sludge treatment technology to increase temperature. Co-composting is an effective ways to reduce pathogens in fecal sludge, while at the same time producing a valuable resource. During the composting process, microorganisms (such as bacteria, yeast, and worms) break down the organic material in the fecal sludge. This process releases heat and kills pathogens. For more information on co-composting see:

Co-composting fecal sludge in a bin

- CAWST's Technical Brief: Sanitation System – Fecal Sludge Treatment Technologies
- CAWST and Eawag-Sandec Co-Composting Treatment Technology Fact Sheet.

There are other fecal sludge treatment technologies that inactivate pathogens through raised temperature. See CAWST and Eawag-Sandec's Treatment Technology Fact Sheets:

- Incineration
- Thermal drying

> **Does Anaerobic Digestion Increase Temperature?**
>
> Treatment technologies that use anaerobic digestion (like a biogas digester) do not increase the temperature. Anaerobic microorganisms feed on organic material and release a gas called biogas. This reaction does not release heat.

4 Moisture

Just like people, microorganisms need water to survive. As moisture drops to a certain level, pathogens will start to die. Fecal sludge naturally has a high water content, even if no flush water or anal cleansing water is used.

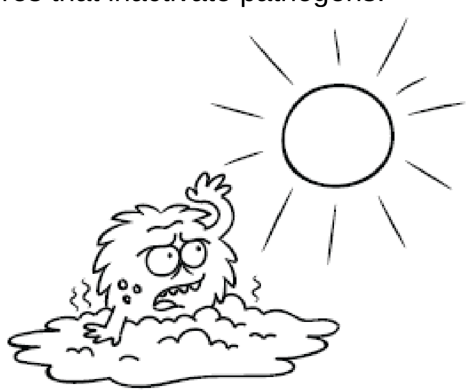
Dewatering removes water from the faecal sludge, mainly through filtration or settling. Drying further removes water through evaporation or using thermal energy (heat). To understand the difference between dewatering and drying, think of a wet towel. You first have to wring the towel (dewatering), then you have to hang your towel to dry (drying).

For more information about fecal sludge treatment technologies that remove moisture, see CAWST and Eawag-Sandec's Treatment Technology Fact Sheets:

- Planted drying bed
- Unplanted drying bed
- Thermal drying

5 Solar Radiation

Sunlight can destroy pathogens with ultraviolet (UV) light and infrared radiation. UV radiation damages and kills living cells. The light rays must reach the pathogens to inactivate them, so this is only effective for pathogens on the surface of the fecal sludge. Infrared radiation heats the sludge to reach temperatures that inactivate pathogens.



Technical Brief: Fecal Sludge Treatment – Pathogen Inactivation Mechanisms

For more information about fecal sludge treatment technologies that remove moisture, see CAWST and Eawag-Sandec's Treatment Technology Fact Sheets about:

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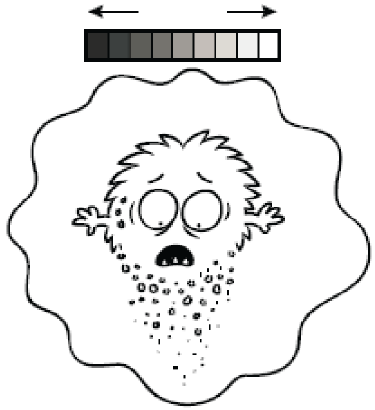
6 pH



The pH is a measure of how acidic or basic (alkaline or caustic) something is. It ranges from pH 0 to 14, with 7 being neutral. A pH less than 7 is acidic and a pH greater than 7 is basic.

Most pathogens can only survive within a range of pH 2 to 3. Also, most pathogens cannot survive below pH 3 or above pH 10 (Strande, Ronteltap & Brdjanovic, 2014). By changing the pH of fecal sludge, pathogens can be inactivated.

The following table shows the WHO recommendations for pH levels needed to reduce pathogens in fecal sludge.

Table: WHO pH Treatment Recommendations

pH	Time	Pathogen Reduction
Above pH 9	At least 6 months	• Inactivation of all pathogens will take longer if the fecal sludge is wet and/or the pH is lower

(WHO, 2006)

It is important to note that changing the pH can also have a negative impact on other biological processes. For example, it can disrupt aerobic and anaerobic digestion for treating fecal sludge.

What Chemicals Can Be Used to Change pH?

The following chemicals are often used to change the pH of domestic wastewater: chlorine, ozone, acids, alkalines (such as lime), and urea.

Based on the experience with domestic wastewater, treating fecal sludge with chemicals is starting to be researched and implemented, in particular using alkalines (lime) and urea. For more information, see CAWST and Eawag-Sandec's Treatment Technology Fact Sheet: Alkaline Treatment.

Technical Brief: Fecal Sludge Treatment – Pathogen Inactivation Mechanisms

7 Additional Resources

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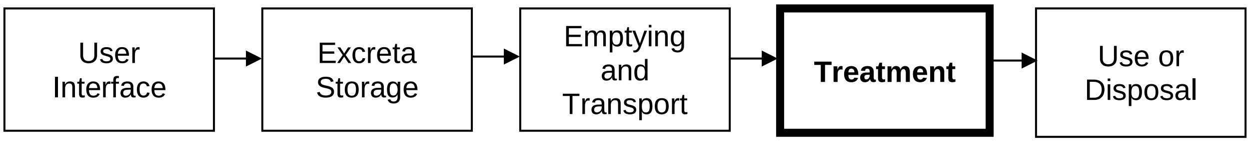
Technical Brief: Sanitation System – Fecal Sludge Treatment



Contents

Technical Brief: Fecal Sludge Treatment

1 Introduction

A sanitation system deals with human excreta from the time it is generated until it is used or disposed of safely. The fourth component of the sanitation system addresses treating fecal sludge to reduce the health and environmental risks. A lack of available and low cost treatment options contributes to harmful fecal sludge being dumped into the environment. This reduces the benefits of building on-site sanitation technologies in the first place.

The type and level of treatment will depend on the final goal for the fecal sludge. Treatment can mean reducing the pathogens to a safe level. Or it can be transforming fecal sludge into a valuable product with economic and environmental benefits. Using a product rather than creating waste is called “resource recovery”. Treatment helps to manage and reduce negative impacts of fecal sludge, as well as increase the potential positive impacts.

This Technical Brief introduces the importance of fecal sludge treatment and explains different treatment objectives, including pathogen inactivation, dewatering, nutrient management, and stabilization. It also gives an overview of emerging and established technologies available to treat fecal sludge.

This document provides a technical overview and is not a design manual. An experienced professional should be consulted for the design of specific treatment technologies.

CAWST focuses on the planning, design, and implementation of on-site sanitation projects for low-income communities not connected to a sewer. For such communities, household or decentralized sanitation offers a hygienic and affordable solution.

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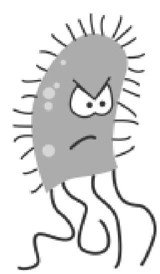
2 What Are the Objectives of Treatment?

The type and level of treatment will depend on the final goal for the fecal sludge. There are four main treatment objectives: (1) pathogen inactivation, (2) dewatering, (3) stabilization, and (4) nutrient management.

1. **Pathogen inactivation:** A key objective of fecal sludge treatment is often pathogen reduction to protect public health. Pathogens are bacteria, viruses, protozoa and helminths that cause disease. The level of pathogen reduction required depends on the final use or disposal of the fecal sludge. For example, sludge applied to crops needs more treatment to reduce pathogens than if it is buried.



   Fecal sludge treatment inactivates pathogens in various ways. The mechanisms are described in CAWST’s Technical Brief: Fecal Sludge Treatment – Pathogen Inactivation Mechanisms.

More information about pathogens can be found in CAWST's Technical Brief: What is Fecal Sludge?

2. **Dewatering**: Fecal sludge naturally has a high water content. Dewatering removes water from the fecal sludge. The term drying is also sometimes used, and suggests an increased level of dryness. To understand the difference between dewatering and drying, think of a wet towel. You first have to wring the towel (dewatering), then you have to hang your towel to dry (drying).

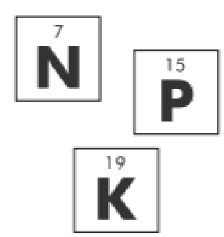
Water is heavy. Dewatering reduces the weight and volume of sludge making it easier, cheaper, and safer to manage. Dewatered sludge also attracts fewer vectors (like flies and rats) and can reduce smells. As well, the more water in fecal sludge, the higher the risk of surface and groundwater contamination. Pathogens in wet fecal sludge will infiltrate into the ground faster and travel farther than pathogens in dry fecal sludge

Dewatering is sometimes needed before using other treatment technologies. For example, if you wanted to compost sludge from a septic tank, you would have to dewater it first. This is because the sludge from a septic tank is very wet, and composting is more efficient with drier sludge. However, not all sludge is easy to dewater. In general, sludge that has not been stabilized is more difficult to dewater (Strande et al., 2014).

3. **Stabilization:** Stabilized fecal sludge means that easily degradable organic material is degraded by microorganisms. Fecal sludge contains a lot of organic material, which can be beneficial for plants, or can be a contaminant in surface water. Stabilized sludge is more predictable, smells less, and contains nutrients that are in a form plants and microorganisms in the soil can more readily use.

If your goal is to produce energy, you will want less stabilized fecal sludge to start with. The breakdown of organic material during stabilization produces energy. In an anaerobic setting, it will produce biogas. In an aerobic setting, it will generate heat. Less stabilized sludge has the potential to produce greater amounts of energy.

4. **Nutrient management:** Fecal sludge contains nutrients, like nitrogen, potassium, and phosphorous. These nutrients are needed for plant growth. Farmers apply them to increase crop yield. However, these nutrients can also infiltrate through soil into groundwater, or be transported by rainwater runoff to surface water bodies. They can contaminate both drinking water and the environment.



Nutrient management generally means changing the form of nutrients (for example, from liquid to solid, or from organic to inorganic). Nutrients are not necessarily removed during treatment, but transformed. When organic material is stabilized, nutrients are also stabilized (meaning they are taken up and incorporated into organic material).

The form of the nutrient is important for managing the fecal sludge and protecting the environment. For example, nitrogen in an organic form (for example, compost) is stable and slowly released. It can be directly applied to crops and beneficially used. Whereas nitrogen in an inorganic or ionic form (for example, nitrogen found in leachate) can have negative impacts. For example, it could harm plants when applied directly, move down through the soil to groundwater, or volatilize into the environment and cause harm.

3 Fecal Sludge Treatment Technologies

There are many technologies available to treat fecal sludge, each with different treatment objectives, treatment products, and level of development.

Fecal sludge treatment is a process. To effectively treat fecal sludge, several treatment technologies may be needed in a particular order. For instance, sludge may have a lot of water, which often needs to be removed before other technologies can be used, like composting or incineration.

The choice of technologies will largely depend on the following factors:

1. **Final goal:** It is important to keep the final goal in mind when selecting appropriate treatment technologies. You first need to know how the sludge will be used or disposed of so you know what treatment is required. For example, you need to focus on dewatering, stabilization and inactivating pathogens to a safe level if you are using fecal sludge for agriculture. However, if the goal is to produce energy, then dryness is important while pathogen inactivation may be a lower priority.

   For more information on use and disposal, see CAWST's Technical Brief: Fecal Sludge Use and Technical Brief: Fecal Sludge Disposal.

2. **Sludge characteristics and quantity:** Sludge from one on-site sanitation technology can be very different than sludge from a different technology. The composition of sludge (what's in it), as well as its consistency (how liquid or solid it is) and quantity will depend on various factors. These include the type and number of on-site sanitation technologies, amount of greywater added, emptying method, and climate. It is important to know the characteristics of the sludge to choose the appropriate treatment technologies. Some treatment technologies, for example, work better with dry sludge (like composting) while others treat wet sludge (like a settling-thickening ponds).

   For more information on sludge characteristics, see CAWST's Technical Brief: What is Fecal Sludge?

3. **Level of technology development:** The level of research and knowledge on treatment technologies can also influence technology selection. Some technologies are well established for fecal sludge treatment, while others are innovative and under development. As well, there are technologies that are being transferred and adapted from wastewater treatment or other sectors for fecal sludge treatment. There is more operational information available for established technologies.

4. **Other factors:** In any given context, the technology choice will also depend on financial resources, cost, local availability of materials, availability of space and land requirements, soil and groundwater characteristics, availability of a constant source of electricity, skills and capacity for design and operation, and management considerations (Tilley et al., 2014).

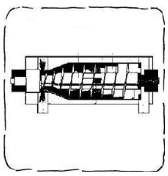
3.1 Solid Waste Removal

On-site sanitation technologies, like pit latrines, are often used as a garbage bin by users. A study done by the pollution research group in Durban, South Africa found various waste products in the latrines. They found plastics (soft and hard), hair wigs, menstrual products, cloth, glass, and metals (Velkushanova, 2015).

Solid waste needs to first be removed from the fecal sludge as part of the treatment process. It can be removed manually or by running the sludge through a screen.

3.2 Dewatering Technologies

The following tables summarize the different dewatering technologies available for fecal sludge.



Mechanical Dewatering	Transferring from wastewater treatment

Design: Mechanical dewatering technologies include belt filter press, frame filter press, screw press, and centrifuge. Mechanical forces dewater fecal sludge (for example, centrifugal force).

Operation: Conditioners often need to be added to the fecal sludge before mechanical dewatering. Conditioners are products that help to dewater the sludge more efficiently.

Level of Dewatering	Level of Pathogen Inactivation	Stabilization and/or Nutrient Management
High	Low	No

Planted Drying Bed	Established technology

Also called planted dewatering beds, vertical flow constructed wetlands, and sludge drying reed beds.

Design: A planted drying bed is filled with filter material, usually gravel at the bottom and sand on top. Plants selected for a specific climate grow in the filter media. The bottom of the bed is sloped and lined with perforated pipes to drain away the liquid (called effluent).

Operation: Planted drying beds operate (semi-)continuously. Fecal sludge is placed on the surface of the bed and the liquid flows through the sand and gravel. The majority of the solid portion of the sludge stays on the surface. Some of the remaining water in the sludge is removed by evapotranspiration. Sludge can be loaded on the beds without removal for a period of years. Depending on the retention time, the dewatered sludge is stabilized.

Level of Dewatering	Level of Pathogen Inactivation	Stabilization and/or Nutrient Management
Medium	Medium	Yes

Technical Brief: Fecal Sludge Treatment

Unplanted Drying Bed

Established technology

Also called sand drying bed.

Design: Unplanted drying beds dewater fecal sludge. An unplanted drying bed is filled with filter material, usually gravel at the bottom and sand on top. The bottom of the bed is sloped and lined with perforated pipes to drain away the liquid (called effluent or leachate).

Operation: Unplanted drying beds are operated in batches. Sludge is placed on the surface of the bed and the liquid flows through the sand and gravel for a period of days. The majority of the solid portion of the sludge stays on the surface. Some of the remaining water in the sludge is removed by evaporation. The dewatered sludge is then removed from the surface manually or mechanically.

Level of Dewatering	Level of Pathogen Inactivation	Stabilization and/or Nutrient Management
High	Medium	No

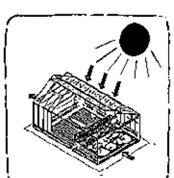
Settling-Thickening

Established technology

Design: Settling-thickening technologies thicken and dewater fecal sludge. Solids settle to the bottom as the fecal sludge flows from one end of the pond or tank to the other. The liquid (effluent) flows through the outlet and requires further treatment. Some solids (for example, fats, oils, and grease) float to the top and form a scum layer. Example technologies include settling-thickening tanks, settlers, Imhoff tanks, and septic tanks.

Operation: Settling-thickening technologies operate (semi-)continuously. Settling-thickening technologies often include two lined ponds or tanks. While one is being operated, sludge thickens in the second. The sludge is then pumped out for further treatment.

Level of Dewatering	Level of Pathogen Inactivation	Stabilization and/or Nutrient Management
High	Low	No



Thermal Drying

Transferring from wastewater treatment

Design: Thermal drying technologies remove more moisture from dewatered fecal sludge.

Operation: Thermal drying technologies operate in batches, continuously or (semi-) continuously. Energy for drying can be solar or through other forms of energy, for example waste heat from industries. Solar drying usually takes place in a greenhouse with transparent covers. Sludge is spread on the floor in shallow basins. The temperature in the greenhouse increases with sunlight and the water in the sludge evaporates. The greenhouse needs to have good ventilation to remove the moist air.

Level of Dewatering	Level of Pathogen Inactivation	Stabilization and/or Nutrient Management
Medium	Medium	No

3.3 Stabilization and Nutrient Management Technologies

Anaerobic Digestion — Transferring from wastewater treatment

Also called a biogas reactor.

Design: Anaerobic digestion stabilizes fecal sludge. It converts fecal sludge into (1) biogas that can be used for energy, and (2) a slurry that can be used as fertilizer.

Operation: Anaerobic digestion is operated (semi-) continuously. Fecal sludge goes in an airtight reactor. Microorganisms break down the organic material in fecal sludge in the absence of oxygen (anaerobic conditions). This process produces methane, also called biogas. Some part of the fecal sludge remains in the reactor following breakdown. This is called digestate and needs to be removed for continuous operation. Fecal sludge can be co-digested with organic material (like food waste and animal excreta) to increase the volume of biogas. Anaerobic digestion is a delicate process to operate, and can be easily upset.

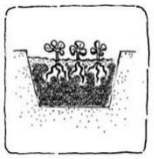
Level of Dewatering	Level of Pathogen Inactivation	Stabilization and/or Nutrient Management
None	Low	Yes

Black Soldier Fly Larvae — Innovative technology

Design: Black soldier fly larvae eat fecal sludge, and in doing so they reduce the volume and stabilize the sludge. Black soldier fly larvae are rich in fat and protein. They are fed to livestock as a source of protein. A black soldier fly does not need to eat once it can fly - in fact it does not have a mouth. Therefore, they are not a vector and do not spread pathogens.

Operation: Black soldier fly larvae treatment is done in batches or semi-continuously. Fecal sludge is placed in a container with black soldier fly eggs or larvae. Other organic waste streams can be added as well to be co-treated. The larvae are harvested periodically to feed to livestock.

Level of Dewatering	Level of Pathogen Inactivation	Stabilization and/or Nutrient Management
None	Low	Yes

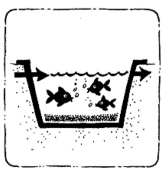


Deep Row Entrenchment | Established technology

Design: Deep row entrenchment is a method of disposal and use as a soil amendment. It requires careful design and operation to not contaminate groundwater.

Operation: Deep row entrenchment is done in batches. Untreated fecal sludge is placed in trenches and then covered with soil. Trees are planted on top or next to the trench. The length and the depth of the trench depend on the highest groundwater level and the quantity of fecal sludge. The trench can be lined, for example with a layer of clay, to reduce the risk of groundwater contamination.

Level of Dewatering	Level of Pathogen Inactivation	Stabilization and/or Nutrient Management
Low	Low	Yes



Fish Pond | Innovative / Transferring from wastewater treatment technology

Design: Fish ponds provide a rich habitat for fish, such as carp, to feed on aquatic plants and organisms. Solids settle to the bottom as the fecal sludge flows from one end of the pond or tank to the other. The liquid (effluent) flows through the outlet and requires further treatment.

Operation: Fish ponds are lined to prevent groundwater contamination. The settled sludge is periodically pumped out for further treatment. Fish and aquatic plants are harvested frequently. The fish can be used as animal feed. Fish must be cooked well if used for human consumption.

Level of Dewatering	Level of Pathogen Inactivation	Stabilization and/or Nutrient Management
Low	Low	Yes

Incineration | Transferring technology

Design: Incineration means that dry fecal sludge is converted into ash at high temperatures (between 850-900ºC). Incineration reduces the sludge volume and kills all pathogens. The ash can be buried, or used for construction material or as a cover material. Dried fecal sludge can fuel industrial processes, such as cement kilns. Incineration produces air emissions, which needs to be controlled to avoid negative environmental impacts.

Operation: Sludge needs to be dewatered before it is incinerated.

Level of Dewatering	Level of Pathogen Inactivation	Stabilization and/or Nutrient Management
High	High	Yes

Technical Brief: Fecal Sludge Treatment

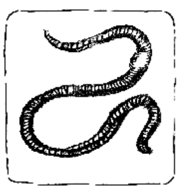
Plant Pond

Innovative / Transferring from wastewater treatment technology

Design: Plant ponds grow aquatic plants using the nutrients in fecal sludge, such as duckweed, watercress, water spinach and water mimosa. Solids settle to the bottom as the fecal sludge flows from one end of the pond or tank to the other. The liquid (effluent) flows through the outlet and requires further treatment.

Operation: Plant ponds are lined to prevent groundwater contamination. The settled sludge is periodically pumped out for further treatment. Aquatic plants are harvested frequently. They can be used as animal feed.

Level of Dewatering	Level of Pathogen Inactivation	Stabilization and/or Nutrient Management
Low	Low	Yes



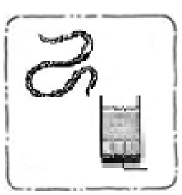
Vermicomposting

Innovative / Transferring from wastewater treatment technology

Design: Vermicomposting stabilizes dewatered fecal sludge. Composting worms break down the organic material as it passes through them. Vermicomposting produces a soil conditioner, which is considered a type of compost.

Operation: Vermicomposting is done in batches or semi-continuously. It requires a bedding layer such as woodchip or straw. The process produces effluent. At a small scale, it can be done in a dark, well-ventilated container, and the effluent is drained. At a large scale, vermicomposting is done in covered piles or rows, and the effluent seeps into the ground.

Level of Dewatering	Level of Pathogen Inactivation	Stabilization and/or Nutrient Management
None	Low	Yes



Vermifilter

Innovative / Transferring from wastewater treatment technology

Design: Vermifilters are filters which contain composting worms. The fecal sludge is added directly to the filters where the composting worms and environment stabilizes the fecal sludge through vermicomposting. Vermicomposting stabilizes dewatered fecal sludge. Composting worms break down the organic material as it passes through them. Vermifilters require a layer of bedding material (where the worms live) and a filtration layer. The bedding material must be made of organic material, such as woodchips. The filtration layer may be made from a variety of materials, such as gravel.

Operation: Vermifiltration is done semi-continuously.

Level of Dewatering	Level of Pathogen Inactivation	Stabilization and/or Nutrient Management
Low	Low	Yes

3.4 Pathogen Inactivation

Co-composting		Established technology
Design: Co-composting stabilizes fecal sludge and inactivates pathogens. Microorganisms break down the organic material in the presence of oxygen. If the process is properly controlled, the temperature of the pile increases resulting in pathogen inactivation, otherwise additional storage or curing is needed to reduce pathogens. The process produces compost, a dark, rich soil-like material, which can be used as a soil conditioner. **Operation:** Co-composing is done in batches. Fecal sludge and other organic material (for example, food waste, wood chips) are placed in piles or rows. Various parameters need to be controlled to ensure an optimal composting process, including temperature, moisture, carbon to nitrogen ratio, and oxygen concentration.		
Level of Dewatering	**Level of Pathogen Inactivation**	**Stabilization and/or Nutrient Management**
Low	High	Yes

Alkaline Treatment		Transferring from wastewater treatment technology
Design: Alkaline treatment increases the pH of fecal sludge and inactivates pathogens, if correctly dosed and mixed. Adding alkaline chemicals is also used to reduce smells, moisture, and flies. **Operation:** Alkaline treatment is usually done in batches. A recommended dosage of alkaline chemicals, such as lime or ash, are added to the fecal sludge and mixed. Dosing depends on the alkaline chemical, sludge water content, and quantity of sludge.		
Level of Dewatering	**Level of Pathogen Inactivation**	**Stabilization and/or Nutrient Management**
None	High	No

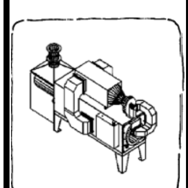
Ammonia Treatment		Innovative technology
Design: High ammonia concentrations are toxic for pathogens and inactivates them. Ammonia could be used from urine or fertilizer. **Operation:** Urea is mixed with fecal sludge in batches. Dosing depends on the required urea concentration, sludge water content, and total solids.		
Level of Dewatering	**Level of Pathogen Inactivation**	**Stabilization and/or Nutrient Management**
None	More research is required	No

Storage		Established technology
Design: Fecal sludge is safely stored to inactivate pathogens. Storage must be planned and monitored, and it is not recommended over other fecal sludge treatment options. **Operation:** Storage is done in batches or (semi-)continuously. Dried fecal sludge is stored in a designated dry area. The conditions must be conducive for pathogen reduction (for example, dryness or temperature) and monitored since specific operating conditions are unknown.		
Level of Dewatering	**Level of Pathogen Inactivation**	**Stabilization and/or Nutrient Management**
Low	High	No

Note: The level of inactivation is based on the proper operation and maintenance of a treatment technology. If a technology is not operated correctly, then the treatment level will be lower.

3.5 Other

Co-treatment with Wastewater		Transferring from wastewater treatment technology
Design: Effluent from fecal sludge treatment technologies usually needs further treatment before discharge into water bodies or use for irrigation. Effluent treatment technologies include waste stabilization ponds, anaerobic baffled reactors, constructed wetlands (also called planted gravel filters), planted drying beds, and anaerobic filters. Effluent can be treated with or without wastewater **Operation**: These technologies cannot be used for treating fecal sludge, but rather effluent coming from other treatment technologies (except planted drying beds).		
Level of Dewatering	**Level of Pathogen Inactivation**	**Stabilization and/or Nutrient Management**
Depends on technology	Depends on technology	Depends on technology



Pelletizing		Transferring from animal feed or biomass fuel production
Design: Dewatered sludge is processed into pellets by pressing it through a nozzle or plate. Pellets are dense, consistent in composition, and relatively easy to store, transport, and market. **Operation:** Pelletizing can be used to enhance drying, for example with the Bioburn process that can process pellets at 50% moisture, that can then dry to 90% without additional thermal energy. Other pelletizers dewater or dry sludge when they are combined with other technologies, such as a thermal dryer in the LaDePa technology. Other pelletizing technologies require that the sludge is first dried, and then compressed into pellets with a binder.		
Level of Dewatering	**Level of Pathogen Inactivation**	**Stabilization and/or Nutrient Management**
Low	Low to High	No

4 Operation and Maintenance

Even well designed treatment technologies often fail because of poor operation and maintenance (O&M). Operation and maintenance can be defined as the following:

- **Operation:** All the activities that are required to ensure that a fecal sludge treatment technology delivers treatment services as designed. Examples of common operations activities are:
    - Adding sludge on to drying beds
    - Removing sludge from settling tanks
    - Removing sludge from drying beds
    - Controlling and emptying screening process
    - Processing (like mixing during composting or adding lime)
    - Collecting and further treating or disposing effluent
    - Storing and selling the treatment products
- **Maintenance:** All the activities that ensure long-term operation of equipment and infrastructure. Examples of common maintenance activities are:
    - Cleaning
    - Controlling corrosion
    - Repacking and exercising valves
    - Oiling and greasing mechanical equipment (for example, pumps)
    - Servicing mechanical equipment (for example, clearing pump screen)
    - Controlling vegetation and pests

Common operation and maintenance challenges observed globally include:

- Lack of financial viability
- Failure of equipment (for example, pumps)
- Weak material supply chains
- Poor operation and maintenance by service contractors (for example, removing sludge from ponds or tanks)
- Contamination from industrial sludge
- Electricity shortages
- Low capacity of staff
- Climate (for example, rainfall)
- Smells

The following table identifies possible solutions to overcome the most common operation and maintenance challenges. A key solution is to develop and implement a detailed operation and maintenance plan, and then have a monitoring program to ensure it is successfully implemented.

Table: Solutions to Overcome Common Operation & Maintenance Challenges

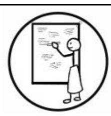
Improve financial viability	Prevent equipment failure	Improve material supply chains	Prevent contamination from industrial sludge
• Identify financial flows within the entire treatment process • Set appropriate sanitation taxes or discharge fees • Investigate or change market for treatment product • Investigate role of public-private partnerships	• Introduce Standard Operating Procedures (SOPs) for all equipment and treatment processes • Introduce a monitoring plan for treatment facilities • Set servicing intervals • Introduce servicing contracts • Increase servicing intervals	• Use materials which can be produced or obtained locally • Use equipment with locally available spare parts • Use equipment which can be repaired locally • Establish supply chains	• Monitor the influent to the treatment facility • Identify “upstream” sources of industrial sludge • Record the origin, volume and special characteristics of fecal sludge in a manifest system • Randomly measure the pH of fecal sludge during discharge • Train fecal sludge treatment operators on the physical inspection of sludge samples

5 Risk Management

Treatment is a barrier that can reduce the risk of pathogen transmission. However, it is difficult to monitor treated fecal sludge and know when it is pathogen-free. There is always a risk. It is therefore important that other protective measures be put in place.

There are many protective measures (also called barriers) that should be put in place when treating fecal sludge. This is often known as a multi-barrier approach. The following table shows barriers that can be used to avoid the spread of pathogens and protect public health.

Table: Protective Measures for Treating Sludge

Barriers to Protect Health		Action
	Use protective equipment	Wear protective equipment, such as clothing, gloves, shoes, and mask. Clean and disinfect the equipment used.
	Wash hands	Wash hands with soap after handling fecal sludge, tools, and equipment.
	Restrict access	Construct a fence to keep children and animals away from the treatment technology. Display warning messages.
	Clean tools	Disinfect the tools used. Safely store the tools so people do not touch them or use them for another purpose.
	Manage effluent	Treat and safely use or dispose effluent. Effluent contains pathogens and can contaminate the environment.
	Train	Train workers on safety precautions and hygiene practices. Train the local community on the purpose and potential hazards of the treatment technology.

Protective Measures used by SOIL, Haiti

SOIL is a nonprofit organization in Haiti that operates fecal sludge composting sites. After identifying the risks of disease transmission and at risk groups, they put in place various protective measures. These include the following:

- Signs are posted throughout the compost site to enforce rules for both staff and visitors. Examples of signs include: No food to be consumed on-site. All vehicles leaving site must disinfect tires. All pedestrians leaving site must disinfect shoes and wash hands.
- An on-site depot is available to store cleaning materials, miscellaneous construction materials, equipment items, and other items. The depot is secured and controlled by the site supervisor.
- Facilities are provided for the staff, including an individual changing room with a door for each staff member, shower, toilet, hand washing station, sanitary zone with table and chairs for resting and eating, and safe drinking water.
- Hygiene infrastructure is available for staff and visitors. This includes a chlorine footbath for disinfecting people's shoes and a chlorine spray station for disinfecting vehicle tires before leaving the site.

(SOIL, 2011)

6 Scale of Treatment

Treatment technologies are generally appropriate for larger user groups (such as from semi-centralized applications at the neighbourhood level to centralized, city level applications). They are designed to accommodate increased sludge volumes and provide, in most cases, improved removal of nutrients, organics and pathogens, especially when compared with small household-level treatment technologies, like composting or dehydrating latrines (Tilley et at., 2014).

CAWST focuses on:

- Household level: treatment done on the household's property
- Community level: small-scale treatment done in the neighbourhood or community

For community level treatment, sludge must be brought to the treatment facility. See CAWST's Sanitation Technical Brief: Emptying and Transporting Fecal Sludge for more information on emptying on-site sanitation technologies and transporting fecal sludge.

7 Knowledge Gap

Knowledge on the various treatment mechanisms and technologies is limited. As research continues, the sanitation sector will grow its knowledge and skills in fecal sludge treatment mechanisms and technologies. The main gaps are the following:

- There is a lack of long-term experience with treatment technologies. Pilot projects on sludge treatment technologies have been carried out all over the world. They are extremely valuable, but are also often small-scale and short-term. This has slowed the sanitation sector from drawing conclusions on the effectiveness, cost, financial sustainability and scalability of different treatment technologies.
- Reliable data and accepted methods for characterizing and quantifying fecal sludge do not yet exist. As well, data from characterization studies also focus on the household level, whereas significant amounts of fecal sludge are generated at public toilets, commercial entities, restaurants and hotels (Strande et al., 2014).
- There are still unknowns about how some treatment technologies inactivate pathogens, particularly with newer technologies.

8 Definitions

Aerobic: Biological processes that occur in the presence of oxygen.

Anaerobic digestion: The decomposition and stabilization of organic material by microorganisms without oxygen. This process produces biogas.

Biogas: Mixture of gases released from anaerobic digestion (without oxygen). It is made up of 50–70% methane, 25–50% carbon dioxide, and varying quantities of nitrogen, hydrogen sulphide, water vapour and other components. Biogas can be collected and burned for fuel.

Characterization: Describing the biological, chemical, and physical properties of fecal sludge.

Dewater: The process of reducing the water content of fecal sludge. Dewatered sludge may still have a significant moisture content, but it is typically dry enough to be handled as a solid (for example, shovelled).

Excreta: Urine and feces not mixed with any flush water.

Fecal sludge: Also called sludge. Excreta from an on-site sanitation technology (like a pit latrine or septic tank) that may also contain used water, anal cleansing materials, and solid waste.

On-site sanitation technology: Also known as a latrine. An on-site sanitation technology is made up of the parts included in the first two components of a sanitation system: user interface and excreta storage. Excreta is collected and stored where it is produced (for example, a pit latrine, septic tank, aqua privy, and non-sewered public toilets). Often, the fecal sludge has to be transported off-site for treatment, use or disposal.

Organic material: Also called organic matter. Comes from the remains of living things, such as plants and animals.

Pathogen: An organism that causes disease.

Stabilization: Degradation of organic material with the goal of reducing readily biodegradable compounds to lessen environmental impacts (such as oxygen depletion and nutrient leaching).

Treatment: Any process to inactivate pathogens, stabilize, dewater, or manage nutrients in fecal sludge.

Wastewater: Used water from any combination of domestic, industrial, commercial or agricultural activities, surface runoff (stormwater), and any sewer inflow (infiltration). Wastewater can be managed on-site or off-site. Wastewater managed off-site is often called sewage.

9 Additional Resources

CAWST Sanitation Resources. Available at: http://resources.cawst.org/

- CAWST's education and training resources are available on a variety of sanitation topics including environmental sanitation; latrine design, siting and construction; fecal sludge management; and sanitation project implementation.

Compendium of Sanitation Systems and Technologies. Tilley, E., Ulrich, L., Lüthi, C., Reymond, P. and Zurbrügg, C. (2014). 2nd Revised Edition. Dübendorf, Switzerland: Eawag: Swiss Federal Institute of Aquatic Science and Technology. Available at: www.eawag.ch/forschung/sandec/publikationen/compendium_e

- The Compendium presents the concept of sanitation systems together with detailed information about sanitation technologies for each component of sanitation systems. The document targets engineers, planners and other professionals who are familiar with sanitation technologies and processes. However, it is also a useful document for non-experts to learn about the main advantages and limitations of different technologies and the appropriateness of different systems.
- The e-Compendium, is an online, interactive version of the Compendium, complete with a tool for combining technologies into a complete sanitation system. Available at: http://ecompendium.sswm.info

Faecal Sludge Management: Systems Approach for Implementation and Operation. Strande, L., Ronteltap, M. & Brdjanovic, D. (2014). London, UK: IWA Publishing. Available at: www.sandec.ch/fsm_book

- This is the first book dedicated to fecal sludge management. It summarizes the most recent research in this rapidly evolving field, and focuses on technology, management and planning. It addresses fecal sludge collection and transport, treatment, and the final end use. The book also goes into detail on operational, institutional and financial aspects, and gives guidance on integrated planning involving all stakeholders. It is freely available online in English and Spanish, and is coming out in French in 2017.

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Akvo images can be retrieved at: http://akvopedia.org/wiki/Main_Page

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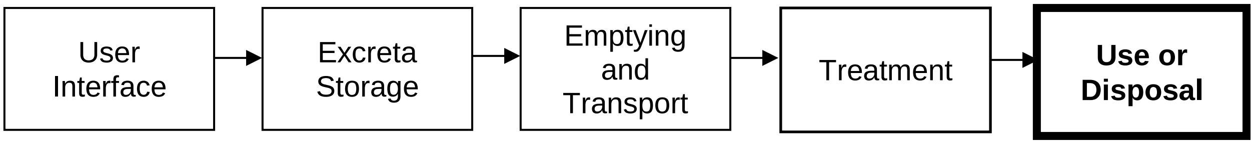

Contents

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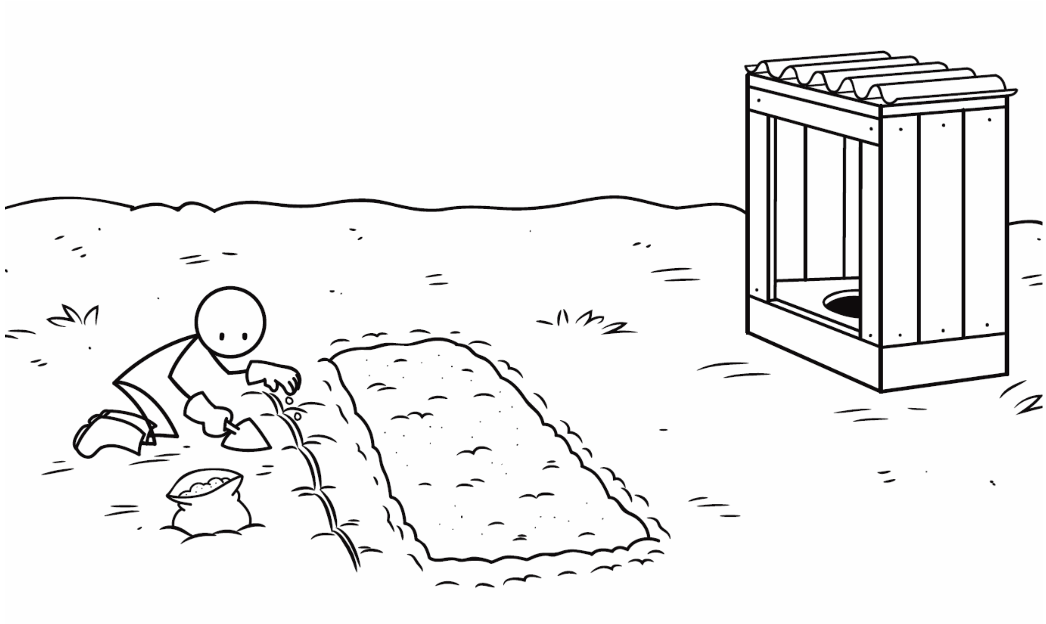
1 Introduction

A sanitation system deals with human excreta from the time it is generated until it is used or disposed of safely. This Technical Brief focuses on the fifth component of a sanitation system: using fecal sludge from on-site sanitation technologies, like a pit latrine or septic tank. As on-site sanitation increases, people are looking for innovative ideas and old traditions to use fecal sludge as a valuable resource.

This Technical Brief introduces the benefits and challenges of using treated fecal sludge for various purposes, including agriculture and energy production. It describes different beneficial uses, along with protective measures to reduce public health and environmental risks.

This document provides a technical overview and is not a design manual. An experienced professional should be consulted for the design of specific fecal sludge use technologies.



Using fecal sludge to grow plants

CAWST focuses on the planning, design, and implementation of on-site sanitation projects for low-income communities not connected to a sewer. For such communities, household or decentralized sanitation offers a hygienic and affordable solution.

CAWST's free, open content resources and schedule of international training workshops can be found at: https://resources.cawst.org and www.cawst.org/training.

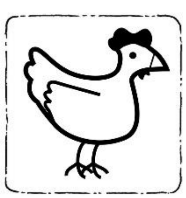
Technical Brief: Sanitation System – Fecal Sludge Use

2 What Can Fecal Sludge Be Used For?

Fecal sludge is transformed by treatment technologies into various products. These treatment products can be a used in ways that have economic and environmental benefits. Using a product rather than creating waste is called “resource recovery”.

Historically, agriculture has been the most common use for fecal sludge. But research is being done on new ways to beneficially use fecal sludge. These uses are summarized in the following table.

Table: Options for Using Fecal Sludge

Fecal Sludge Use		**Description**
	Agriculture and Horticulture	Treated fecal sludge is applied to soil as a soil amendment to improve plant growth by: (1) increasing nutrients, and (2) improving the physical structure of the soil.
	Forestry	Treated fecal sludge is applied to soil to improve plant growth by: (1) increasing nutrients, and (2) improving the physical structure of the soil.
	Irrigation	Effluent from on-site sanitation technologies and fecal sludge treatment technologies is used for irrigating crops to increase nutrients.
	Energy (biogas)	Fecal sludge is mixed with organic waste (like food and garden waste) to produce biogas and digestate. Biogas is primarily used as an energy source for lighting, boiling water and cooking.
	Energy (solid fuel)	Dried fecal sludge can replace other fuels, such as wood and charcoal, which are usually more expensive and damaging to the local environment.
	Livestock	Animals, such as larvae, feed on fecal sludge and provide a protein source for other farm animals and fish. Plants produced from fecal sludge treatment technologies can also be fed to animals (for example, planted drying bed).

Fecal Sludge Use		Description
	Aquaculture	Aquatic organisms, such as fish and aquatic plants, feed on fecal sludge. These aquatic organisms can then be eaten directly, used as animal feed, or used as fertilizer.
	Construction (building materials)	Dried fecal sludge is used to make cement and bricks, and to produce clay-based materials.

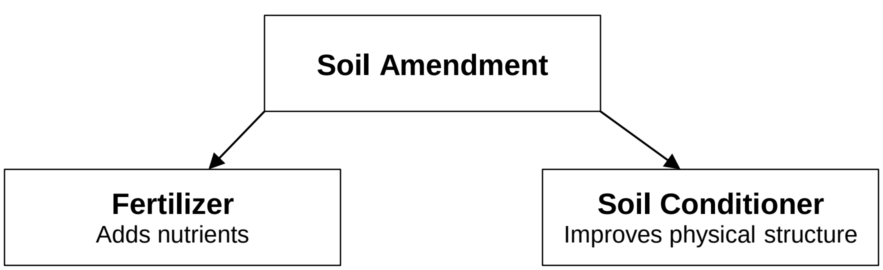
(Illustration credit: Akvo, n.d.)

3 Agriculture, Horticulture, and Forestry

Fecal sludge is most commonly used as a soil amendment in agriculture, horticulture, and forestry. A soil amendment is a general term for any material that improves soil quality. There are various reasons why soil can be of poor quality. The quality of soil can decrease naturally (for example, through erosion) or by human activity (for example, because of intensive agriculture practices). Common problems with poor soil quality include the following:

- Lack of nutrients
- Poor structure (for example, the soil is compacted)
- Cannot hold water
- High salt levels
- Too high or too low pH

Fertilizers and soil conditioners are two types of soil amendments. Fertilizers add nutrients to the soil that plants need to grow. Soil conditioners improve the physical soil structure by increasing the amount of pore space or making the soil less compact, which increases air and water movement and allows better root growth. Soil conditioners also provide a habitat for all the organisms that live below the ground. This ecosystem is vital for plant growth.



3.1 Fertilizers

Fertilizer is used to add nutrients to the soil because plants need nutrients to grow. The three main nutrients plants need, also known as macronutrients, are:

- **Nitrogen (N):** Needed for leaf and stem growth.
- **Phosphorous (P):** Needed for plants to grow flowers and fruits, to make plants more drought-resistant, and help the roots grow.
- **Potassium (K):** Important for root vegetables. It also helps plants resist disease and survive in harsh climates (like cold winters and droughts).

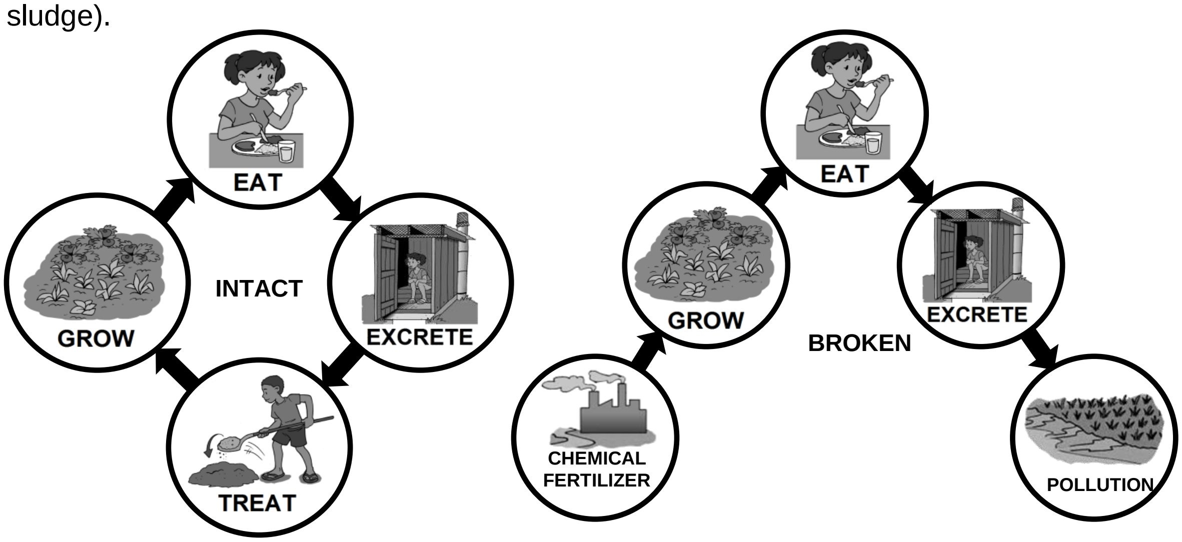
Different types of plants need different amounts of each nutrient. It is important that you know the nutrient demand of your crop. If the right amount of nutrients is applied, the weight of a crop can increase by 2–10 times (Winblad & Simpson-Hebert, 2004). However, too many nutrients can also be toxic for a plant.

To know how much fertilizer to apply, you will also need to know the amount of nutrients in the soil. Often fertilizer manufacturers and distributors for the region have determined this information. If this information is not locally available, you will have to do your own crop trials or use a soil test kit.

3.1.1 Nutrient Cycle

The nutrient cycle helps to explain why using fecal sludge is beneficial for plant growth and the environment. Plants use nutrients from the soil to grow. People and animals then eat the plants and excrete the nutrients through feces and urine. The nutrients in the excreta return to the soil so more plants can grow. However, nutrients are not always available in the form they need to be. Microorganisms need to break down the material and make the nutrients available to plants.

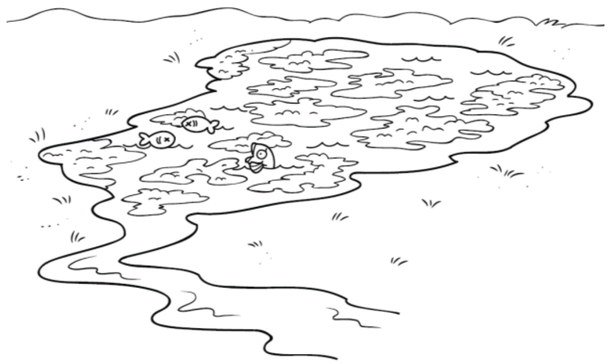
When people grow and harvest crops, many nutrients are removed from the soil. To return nutrients to the soil and continue to grow crops, farmers often add animal excreta (also called manure or dung). In many societies, it is also acceptable to use human excreta (or fecal sludge).



Intact and broken human nutrient cycles

However, in many parts of the world, we have broken this natural nutrient cycle. The nutrients in excreta are no longer returned to the soil to grow crops. Rather, they are often dumped or discharged into surface water bodies. Breaking the nutrient cycle has caused the following environmental and public health issues:

- **Surface water quality:** High concentrations of nutrients and organic material in surface water damages the aquatic ecosystem and is disruptive to livelihoods (for example, fishing and tourism). Algae in the water feed on the nutrients and reproduce rapidly, called an algal bloom. The algae blocks the sunlight from penetrating the water, and other aquatic plants are unable to grow. When the algae dies and is eaten by other organisms, the oxygen in the water is used up and aquatic organisms (like fish) suffocate. This is known as eutrophication. When oxygen is depleted to low levels, this is called anoxic water.



Eutrophication of surface water kills fish

- **Drinking water quality:** Nutrients can also contaminate drinking water and impact our health. For example, nitrates (a form of nitrogen) in drinking water can cause methemoglobinemia, a condition which decreases the amount of oxygen transported through our blood. Infants who are bottle fed with formula prepared with nitrate contaminated drinking water are most at risk. See CAWST's Fact Sheets on the Chemical Parameters of Drinking Water Quality for more information about nitrogen.
- **Soil quality:** Poor soil quality from the lack of nutrients leading to soil degradation.
- **Other forms of pollution:** Manufacturing chemical fertilizers consumes energy and creates other forms pollution.

3.1.2 Chemical Fertilizers

Chemical fertilizers are known to contaminate the environment when poorly managed. But chemical fertilizers also have many advantages that shouldn't be ignored. They provide high crop growth rates and yields to meet the global food demand. Food grown with nitrogen fertilizers feeds an estimated two billion people worldwide (Fields, 2004). Chemical fertilizers are also easy to store, transport, and apply. As well, they are nutrient specific, which means that a farmer can choose the content and amount of nutrients to meet the specific needs of the plants.

Where Do Chemical Fertilizers Come From?

Both phosphorous and potassium are mined from the earth. But they are not available everywhere around the world. In fact, 90% of phosphorous reserves are found in just five countries: China, Jordan, Morocco, South Africa, and the United States (Rosmarin, de Brujine & Caldwell, 2009). And only 12 countries extract and export potassium (The Fertilizer Institute, 2008).

Nitrogen is produced by capturing the nitrogen from the air using a complex chemical reaction. A lot of energy is needed to carry out this chemical reaction. China, India, Russia, and the USA are the leading countries that produce nitrogen-based fertilizers (The Fertilizer Institute, 2008).

Fecal sludge cannot completely replace chemical fertilizers. Annually, about 130 million of chemical fertilizers are sold globally. Of this amount, 78 million tonnes are nitrogen and 13.7 million tonnes are phosphorous. The excreta from 6 billion people contains 27 million tonnes of nitrogen and 3 million tonnes of phosphorous. So in theory, about 35% of the nitrogen fertilizer could be replaced by nitrogen from excreta. Similarly, 22% of the mined phosphorous could be replaced by phosphorous from excreta (WHO, 2006).

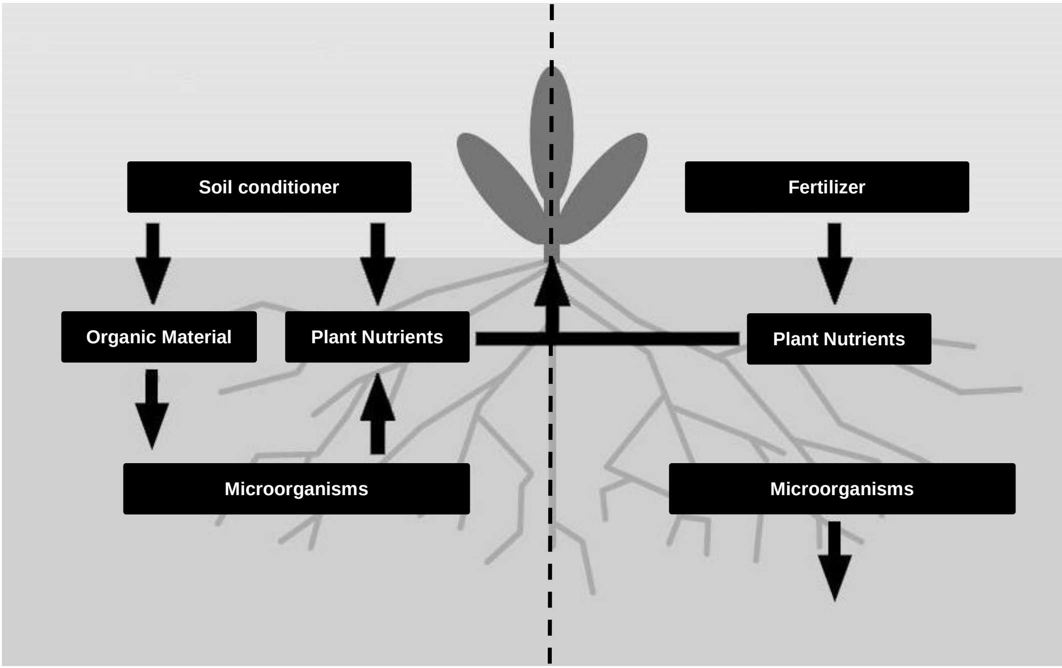
3.2 Soil Conditioners

Farmers often focus on using fertilizers to increase crop growth. However, adding soil conditioners, particularly organic material, can be just as important. Soil conditioners improve the physical soil structure by increasing the amount of pore space or making the soil less compact. This extra space increases air and water movement in the soil and allows better root growth.

Soil conditioners can improve the soil's ability to hold water. Just like any other living thing, plants also need water. Plants get their water from the soil. The soil acts like a sponge and absorbs and retains the water. However, certain soils do not hold water as well as others. This is often due to poor agricultural practices that deplete the soil of organic material.

The importance of having enough organic material in the soil includes the following:

- Provides a habitat for microorganisms; they keep the soil loose and make nutrients available for plants
- Regulates water, pH, temperature, and nutrients
- Reduces crusting at the soil surface
- Reduces pests and plant diseases
- Neutralizes toxins and heavy metals



The importance of soil conditioner in addition to fertilizer (Adapted from Soil Atlas, 2015)

4 Irrigation

Effluent from on-site sanitation technologies and faecal sludge treatment technologies can be used in irrigation. Effluent, also known as leachate, is the general name for a liquid that is produced by an on-site sanitation technology, like a septic tank. Effluent can also be produced from fecal sludge treatment technologies. Effluent is typically high in nitrogen and pathogens. It may also contain other nutrients, heavy metals, and salts (Strande et al., 2014).

As the world population continues to grow and water scarcity increases, there is more awareness on water conservation. Treated effluent can be used to irrigate home gardens or agricultural crops. This can help communities to grow more food, while at the same time conserve precious water. Effluent should be treated before it is used to reduce the risk of transmitting pathogens.

Watch the Salt!

Using effluent for irrigation will increase the salinity of the soil over the long-term. Salt can interfere with plant growth and have long-term impacts on the soil. It is recommended that salinity control practices are used, like making sure that there is enough drainage.

(Strande, Ronteltap & Brdjanovic, 2014; WHO, 2006)

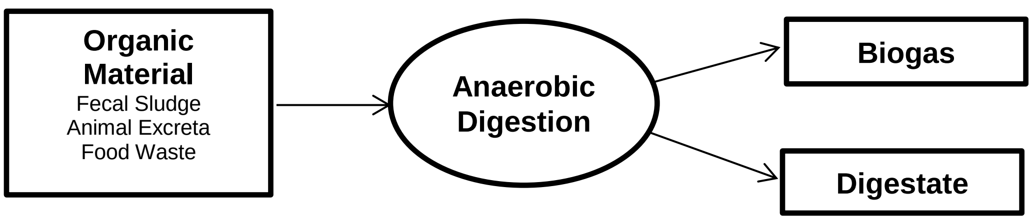
Effluent treatment technologies include waste stabilization ponds, anaerobic baffled reactors, constructed wetlands (also called planted gravel filters), planted drying beds, and anaerobic filters. Effluent can be treated with or without wastewater.

For more information about effluent management see CAWST's Technical Brief: Effluent Management. Also, see CAWST and Eawag-Sandec's Treatment Technology Fact Sheet: Co-Treatment with Wastewater.

5 Energy – Biogas

Biogas is produced when microorganisms eat organic material in an environment with no oxygen (called anaerobic). These microorganisms are called anaerobic microorganisms and the process is called anaerobic digestion.

Biogas is made of 60% methane (CH_4) and 40% carbon dioxide (CO_2). The material that is left after the microorganisms have eaten most of the organic material is called digestate (also called slurry). It contains a lot of nutrients and can be used as a fertilizer if further treated. Think of the human stomach to understand the anaerobic process. We eat food (organic material) that enters our stomach. There is no oxygen in our stomach. After we digest our food we produce both gas and excreta.



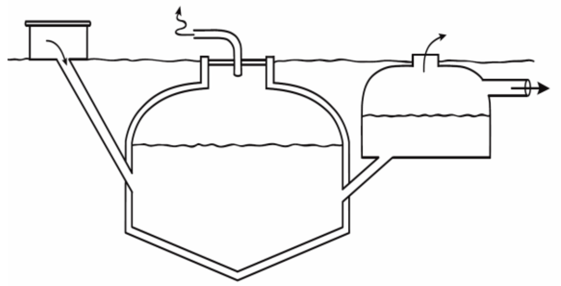
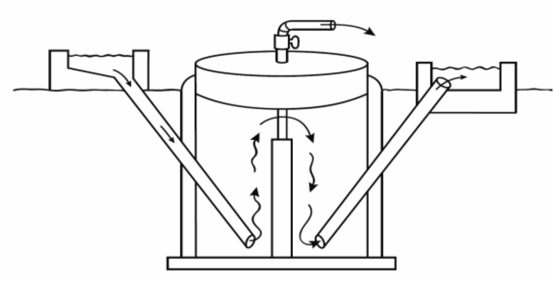
Products of anaerobic digestion

Anaerobic digesters (also called biogas digesters or reactors) have been built all over the world. Countries with extensive programs include China, India, Kenya, Nepal, Sri Lanka, and various countries in Latin America. China is a leader in biogas production with over 7.5 million household anaerobic digesters as well as 750 larger scale production facilities (Bates, 2007).

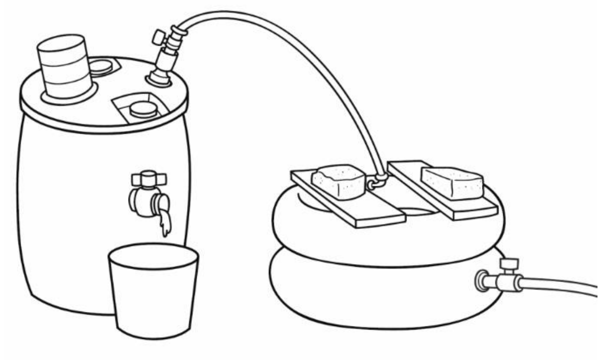
An anaerobic digester is made of an inlet pipe, an outlet pipe, a biogas tank, a collecting tank, and a biogas pipe. Fecal sludge, along with other organic material like animal excreta and food waste, is dumped in the inlet pipe and transported to the digestion tank. Biogas forms in the mixture and rises to the top of the tank. The biogas then flows out through a pipe. There is usually a valve on the pipe that can be opened and closed when gas is needed. As pressure increases, digestate is pushed into the collecting tank, which has an access door to remove the digestate. For more information on the design, operation and maintenance, see CAWST and Eawag-Sandec's Treatment Technology Fact Sheet: Anaerobic Digester.

There are generally two types of anaerobic digesters: the fixed dome (also known as the Chinese reactor) and the floating dome (also known as the Indian reactor). The following table compares the different designs.

Table: Common Biogas Reactor Designs

Fixed Dome	Floating Dome
The volume, or space available, does not change and pressure builds up. The more gas produced, the higher the pressure in the tank. The fixed dome reactor is common for households and small-scale use.	The dome on top of the tank floats up and down depending on the volume of gas in the tank. If the volume of gas increases, the dome is pushed up. If gas is used, the dome will descend.
	

More designs for simple household anaerobic digesters are being tested and developed. Many are made with local materials like plastic barrels and pipes, like the one shown in the following figure. Minimal tools and skills are required to make them.

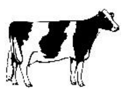


Simple anaerobic digester design

To produce a significant volume of biogas, fecal sludge needs to be mixed with food waste and animal excreta. Anaerobic microorganisms like different types of waste. They will quickly digest the waste they really like. If they don't particularly like a type of waste, they will eat it a lot slower.

How Much Biogas Can a Household Produce?

One person's excreta (0.4 kg) produces about 20 litres of biogas per day (NWP, 2006). One person needs about 300–900 litres of biogas per day to cook all of their meals (ISAT & GTZ, 1999).



1 kg cattle excreta produces 40 litres of biogas (Mang, 2005). Cattle produce about 30 kilograms of excreta each day, producing 1,200 litres of biogas (Statistics Canada, 2015).

A household will not produce enough biogas just using human excreta. However, a household with one cow could produce enough biogas needed for their daily cooking.

Microorganisms also have preferences for excreta. As shown in the following table, they like chicken excreta more than human and cattle excreta. Microorganisms also prefer different types of human excreta. For example, they do not particularly like old human excreta from ventilated improved pit (VIP) latrines. The excreta from a VIP latrine is often fairly stabilized (Bakare, 2014). This means that there the organic material has already been broken down. Therefore, the anaerobic digester will not produce much biogas if it is only fed stabilized sludge.

Table: Biogas Production of Human and Animal Excreta

1 kg of Excreta	Litres of Biogas Produced
Human	50
Cattle	40
Chicken	70

(NWP, 2006)

6 Energy – Solid Fuel

Using fecal sludge to make solid fuel is increasing as an alternative to common fuel sources like wood and charcoal. As common fuel prices increase, there is more interest in new fuel sources, such as fecal sludge. As well, there are less pathogen transmission routes using sludge as a fuel than using it for agriculture. It is, therefore, not subject to strict regulations.

People have made fuel briquettes, pellets and cakes using various waste products, like animal excreta. However, using fecal sludge to make solid fuel is a relatively new science.

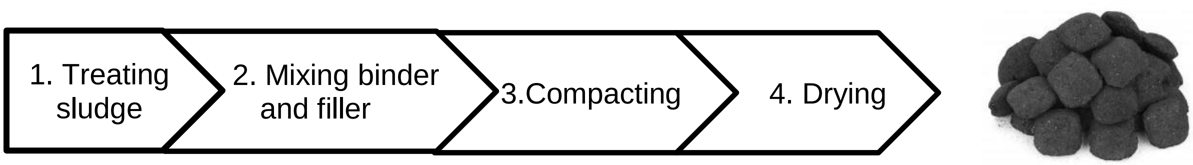
Fecal sludge produces similar energy to wood and charcoal (Niang, Seck, Diene, Gold & Strande, 2015). The heating ability of a material is expressed in calorific value. The unit for this measurement is joules per kilogram of dry material. As shown in the following table, dry fecal sludge can produce more heat than wood and it is within the same range as charcoal.

Table: Calorific Value of Various Solid Fuels

Material	Calorific Value (Megajoules per kilogram of dry material)
Straw and hay	16
Charcoal	8–32
Wood	14–18.8
Dry fecal sludge	22

(Niang et al., 2015)

There are four stages to produce briquettes: (1) treating the fecal sludge, (2) mixing binder and filler with the sludge, (3) compacting the material, and (4) drying the briquettes.



Four stages to produce fuel briquettes

The sludge needs to first be treated to reduce the water content and pathogens. This is usually done by increasing the temperature of the sludge. Sanivation, an organization based in Kenya, is using solar energy to heat the fecal sludge and kill the pathogens (Sanivation, 2015). Dried feces can also be carbonized using a kiln to reduce the smoke released by the briquette and ensure all pathogens are inactivated. Carbonization is when fecal sludge is heated to high temperatures in the absence of oxygen. The material is not turned to ash, but breaks down. The end products are char, oils, and gases (Lohri, Sweeney & Rajabu, 2015).

The dried sludge then needs to be mixed with a binding agent to hold the briquette together (Village Volunteers, n.d.). You need some moisture to mix all the components together. The binding material is a fibrous organic material. It should be cheap and locally available year round. Materials with a lot of starch have proved to be very effective, such as corn, wheat, and certain vegetable peels (Nyer, 2012). They use waste from the flower industries as the main component of their briquettes.

Depending on fecal sludge characteristics and the treatment method, the sludge may also need to be mixed with a filler. The filler makes it easier to maintain a flame. Examples of fillers are sawdust, coffee husks, coffee pulps, or even charcoal fines. The mixed materials are then formed into briquette shapes using a press and dried. The final briquettes should have a dryness of 90% to burn most efficiently (Gold et al., 2014).

7 Livestock

7.1 Animal Protein

Fecal sludge can also be fed to high-protein animals, like black soldier fly larvae, to then feed farm animals, such as chickens. Farmers use a lot of their budget to feed their animals. They commonly buy soybeans, canola, cereal by-products, meat and bone as well as fish to provide protein for their animals. However, new animal feeds are being tested to be cheaper and more efficient than the common animal feeds.

Using black soldier fly larvae is a fairly new and simple approach to animal feed. Farmers place the fly larvae inside a bin. They feed the larvae excreta and other organic waste. The larvae grow as they eat the excreta and organic waste. This growing period can vary between 2–8 weeks, depending on the amount of food they are fed and the climate (Warkomski, 2015). Before the larvae become adult flies, they are collected and fed to farm animals. There is little research on the risk of disease transmission by feeding the larvae to animals. Recent research showed certain pathogens, such as *Enterococcus* and *Ascaris*, are not inactivated through this process (Lalander et al., 2013). Farmers should therefore treat the fecal sludge before feeding it to the larvae.

See CAWST and Eawag-Sandec's Treatment Technology Fact Sheet: Black Solider Fly for more information.

Aren't Black Soldier Flies a Vector?

Flies are usually a vector for spreading diseases. However, the black soldier fly has an advantage. It does not eat once it is adult size and can fly. In fact, it has no mouth. These flies are not attracted to feces or food. They are, therefore, not a vector.

7.2 Plants

Fecal sludge can also be treated using a planted drying bed to produce plants for animal feed. Plants are carefully chosen for the climate and to grow under the conditions in the drying bed (Strande, et al., 2014). The most frequently used plant is one type of reed called *Phragmites australis* (De Maeseneer, 1997; Hardej and Ozimek, 2002). Harvesting the plants happens when the technology is desludged and plants are cut at the surface of the drying bed (Strande, et al., 2014).

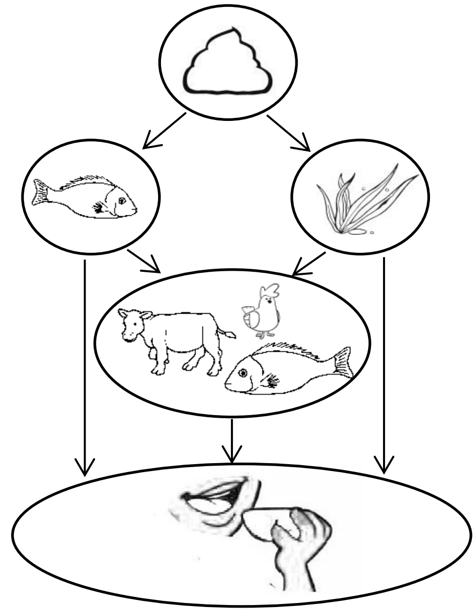
See CAWST and Eawag-Sandec's Treatment Technology Fact Sheet: Planted Drying Bed for more information.

8 Aquaculture

Fecal sludge can also be fed to aquatic organisms such as fish (for example, carp) and aquatic plants (for example, water mimosa, water spinach, watercress, water chestnut and duckweed). Aquaculture is usually for human consumption, but some aquatic plants and fish can be fed to other fish or livestock.

Aquaculture is an old tradition, particularly used in Asia still to this day. Aquatic plants are an important part of the diet in Southeast Asia and is important for food security (WHO, 2006b).

Aquaculture can be intentional or unintentional. Unintentional aquaculture is more common around the world. It occurs when there is illegal dumping of wastewater or fecal sludge in a water body. This can be in a lake, river, small pond or in the ocean. Farmers cage the fish and install stakes to grow plants in these water bodies. This makes it easier for them to catch the fish and harvest the aquatic plants.



Aquaculture food chain

Fecal sludge used for aquaculture should be treated first. Therefore, overhanging toilets are not recommended. These are toilets built above the water and the excreta falls directly into the water. This practice is quite common in Southeast Asia.

See CAWST and Eawag-Sandec's Treatment Technology Fact Sheets: Fish Pond and Floating Plant Pond for more information.

The Art of Aquaculture

Some call aquaculture an art form more than a science. It is very difficult to maintain optimal conditions for aquaculture. A water body can quickly accumulate too much organic material or nutrients which damages the aquatic ecosystem. There is also very little scientific information on aquaculture.

9 Building Materials

Dried fecal sludge can be used to make cement and bricks, and to produce clay-based materials. Dried fecal sludge has been shown to have similar qualities as other building materials, like limestone and clay materials.

In Japan, dried fecal sludge is commonly used as an alternative fuel in the kiln to produce cement. The ash from incinerating fecal sludge is also incorporated into the cement (Strande, et al., 2014).

Bricks made from dried fecal sludge

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Pathogen transmission is less of a concern when fecal sludge is used as a building material since human contact is reduced. As well, the pathogens are killed by high temperatures during the manufacturing process.

10 Risk Reduction

People can potentially get sick when using fecal sludge through different transmission routes, such as:

- Direct contact when handling fecal sludge
- Contact with soil contaminated with fecal pathogens. This is particularly important in agriculture and areas where *Ascaris lumbricoides* (a type of roundworm) is present.
- Contact with water contaminated with fecal pathogens. This is particularly important in aquaculture and areas where schistosomiasis is present.
- Eating food or drinking water contaminated with fecal pathogens.

For more information on *Ascaris,* schistosomiasis and other fecal pathogens, see CAWST's Technical Brief: What is Fecal Sludge?

Fecal sludge should be treated first to inactivate pathogens before it is used. However, it can be difficult to treat and monitor fecal sludge to ensure that it is safe to use. See CAWST's Technical Brief: Fecal Sludge Treatment and Technical Brief: Fecal Sludge Treatment Mechanisms for more information.

As such, several barriers can be put in place after treatment to minimize the risk of transmitting fecal pathogens while it is being used. These barriers focus on protecting the people handling the fecal sludge (like farmers), those eating the food or using the product (consumers), and the local community. This is often known as a multi-barrier approach to prevent or eliminate a sanitation-related risk, or reduce it to an acceptable level (WHO, 2016).

Table: Barriers to Protect Health

Barriers to Protect Health		**Action**
	Crop restriction	Only use treated faecal sludge for crops that: • Are not eaten (like cotton) • Are processed (like wheat) • Are cooked (like potatoes) • Do not directly touch the ground (like bananas)
	Application techniques	Mix treated faecal sludge into the soil and then cover with soil. Do not apply directly on the plant.
	Use protective equipment	Wear protective equipment, such as clothing, gloves, shoes, and mask.
	Waiting period	Wait one month after applying the fecal sludge before harvesting crops. Pathogens continue to be inactivated once they are in the soil. Inactivation is much faster in hot and sunny climates than cold and rainy climates.

Barriers to Protect Health		Action
	Prepare food properly	Wash fruits and vegetables with safe water before eating. Wash hands with soap before cleaning and preparing food. Cook all food thoroughly and do not eat raw food.
	Wash hands	Wash hands with soap after handling fecal sludge, tools, and equipment.
	Clean tools	Disinfect the tools used to handle fecal sludge, and only use them for this activity. Safely store the tools so people do not touch them or use them for another purpose.
	Train	Train sanitation service providers, farmers, families, and the community on best fecal sludge management and hygiene practices.
	Deworm	Provide treatment for helminth infections to sanitation service providers, farmers, and their families. This will help to break the transmission cycle and reduce helminths in excreta.

As well, the World Health Organization (WHO) has developed the Guidelines for Safe Use of Wastewater, Excreta and Greywater in 2006. They provide a comprehensive framework for managing health risks associated with using human waste in agriculture and aquaculture.

Case Study: Hanam, Vietnam

A study was conducted in the community of Hanam, Vietnam to assess the relationship between agricultural use of excreta/wastewater and diarrhea. Over one year, diarrhea incidences were monitored for adults without direct contact to excreta/wastewater and adults with direct contact. The study concluded that adults with direct contact had a higher incidence of diarrhea. Some of the risk factors identified were:

1. Using no protective measures
2. Composting human excreta for less than three months
3. Never washing hands with soap

(Pham-Duc et al., 2014)

11 Knowledge Gap

Knowledge on how to use fecal sludge safely is limited. The main gaps are the following:

- There is a limited research on the health risks of using fecal sludge. It has led governments to set unrealistic targets or avoid creating standards at all. Most countries, for example, do not have standards for using fecal sludge in agriculture (Johansson & Kvarnstrom, 2005). Standards for using wastewater in agriculture are more likely to exist because there is more research on wastewater than fecal sludge.

- Other than using feces and urine for agriculture, other innovative uses are in experimental stages or being tested at a pilot or small-scale. More research is needed to improve these new technologies, particularly in terms of cost and sustainability.
- There is limited research on the effects of trace organics (such as natural hormones, synthetic hormones, and pharmaceuticals) in fecal sludge on the environment and public health. Researchers have only recently begun to study whether and how trace organics affect living things in the environment and what this means for public health.

12 Definitions

This section includes key definitions in this Technical Brief. For a complete list of sanitation terms and definitions see CAWST's Guide to Sanitation Resources or http://www.cawst.org/WASHglossary.

Aerobic: Biological processes that occur in the presence of oxygen.

Anaerobic digestion: The decomposition and stabilization of organic material by microorganisms without oxygen. This process produces biogas.

Anaerobic digester: Also called a biogas digester or biogas reactor. A technology that uses the process of anaerobic digestion to produce biogas.

Chemical fertilizer: Also called artificial, synthetic or commercial fertilizers. A material produced by industry containing nutrients that plants need to grow.

Ecological sanitation: Also called ecosanitation, ecosan, resources-oriented sanitation or productive sanitation. An approach that aims to safely recycle nutrients, water and energy from excreta and wastewater. This is done in a way that minimizes the use of non-renewable resources.

Effluent: Also called leachate. Liquid that is produced from an on-site sanitation technology (like a septic tank) or fecal sludge treatment technology.

Excreta: Urine and feces not mixed with any flush water.

Fecal sludge: Also called sludge. Excreta from an on-site sanitation technology (like a pit latrine or septic tank) that may also contain used water, anal cleansing materials, and solid waste.

On-site sanitation technology: Also known as a latrine. An on-site sanitation technology is made up of the parts included in the first two components of a sanitation system: user interface and excreta storage. Excreta is collected and stored where it is produced (for example, a pit latrine, septic tank, aqua privy, and non-sewered public toilets). Often, the fecal sludge has to be transported off-site for treatment, use or disposal.

Organic material: Also called organic matter. Comes from the remains of living things, such as plants and animals.

Pathogen: An organism that causes disease.

Risk: The likelihood of a hazard causing harm to exposed populations in a specific time frame and the consequences of that harm.

Soil amendment: Anything mixed into soil to improve soil quality and support healthy plant growth. Fertilizers and soil conditioners are two types of soil amendments. Fertilizers add nutrients to the soil that plants need to grow. Soil conditioners improve the physical soil structure.

Treatment: Any process to inactivate pathogens, stabilize, dewater, or manage nutrients in fecal sludge.

13 Additional Resources

CAWST Sanitation Resources. Available at: http://resources.cawst.org/

- CAWST's education and training resources are available on a variety of sanitation topics including environmental sanitation; latrine design, siting and construction; fecal sludge management; and sanitation project implementation.

EcoSanRes Series. Available at: www.ecosanres.org/publications.htm

- EcoSanRes was a five-year program that developed evidence-based publications on ecological sanitation. The program focused on capacity building and knowledge management.

Faecal Sludge Management: Systems Approach for Implementation and Operation. Strande, L., Ronteltap, M. & Brdjanovic, D. (2014). London, UK: IWA Publishing. Available at: www.sandec.ch/fsm_book

- This is the first book dedicated to faecal sludge management. It summarizes the most recent research in this rapidly evolving field, and focuses on technology, management and planning. It addresses faecal sludge collection and transport, treatment, and the final end use. The book also goes into detail on operational, institutional and financial aspects, and gives guidance on integrated planning involving all stakeholders. It is freely available online in English and Spanish, and is coming out in French in 2017.

Guidelines for Safe Use of Wastewater, Excreta and Greywater. WHO (2006). Geneva, Switzerland: World Health Organization. Available at: www.who.int/water_sanitation_health/wastewater/gsuww/en/

- The Guidelines provide a comprehensive framework for managing health risks associated with using human waste in agriculture and aquaculture. They were designed to assist in developing national and international approaches (like policies and legislation), and to provide a framework for national and local decision making to identify and manage health risks.

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Compendium images can be retrieved at: www.eawag.ch/en/department/sandec/publications/compendium/

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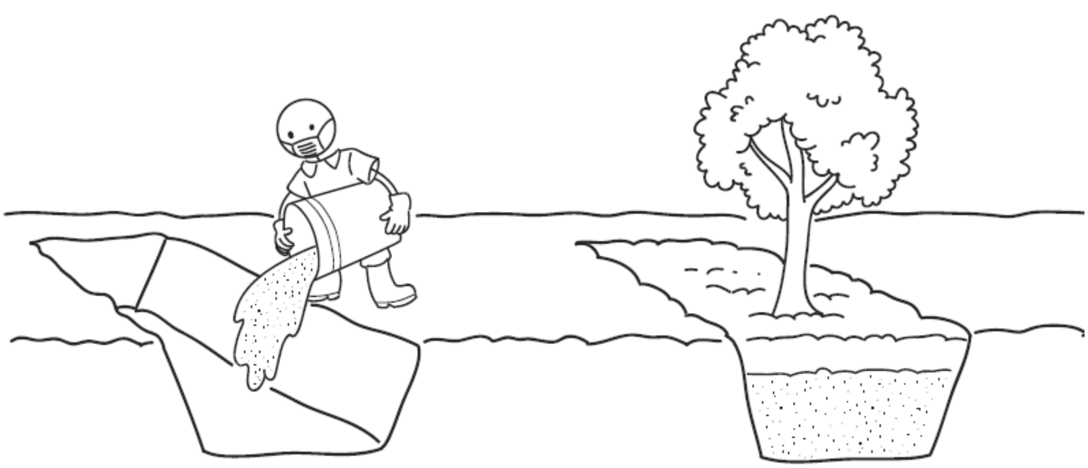
Wellness through Water.... Empowering People Globally
Last Update: July 2016

CAWST
Centre for Affordable Water and Sanitation Technology

Technical Brief: Sanitation System – Fecal Sludge Disposal

User Interface → Excreta Storage → Emptying and Transport → Treatment → **Use or Disposal**

Contents



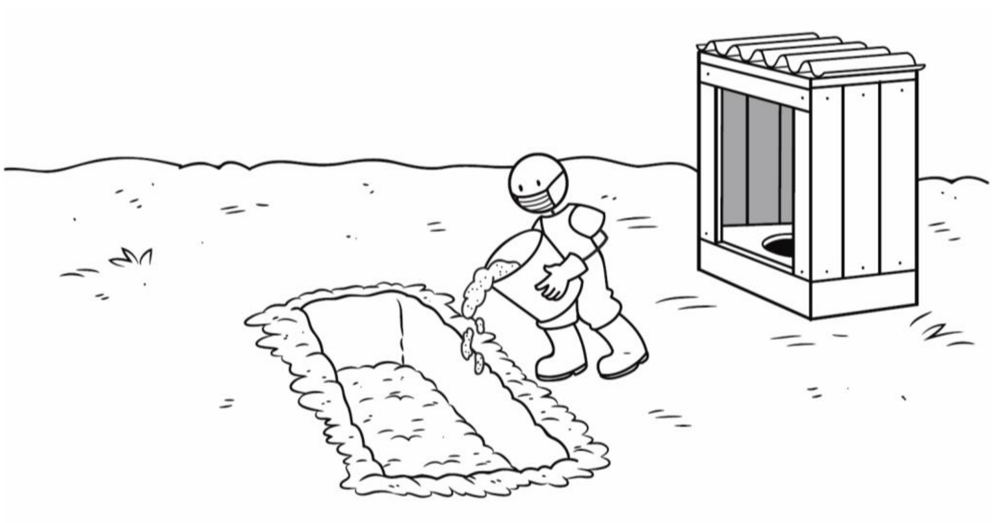
Technical Brief: Fecal Sludge Disposal

1 Introduction

A sanitation system deals with human excreta from the time it is generated until it is used or disposed of safely. The fifth component of the sanitation system addresses how fecal sludge can be disposed of to minimize public health and environmental risks. The capacity to treat and use fecal sludge often does not exist. This leads to harmful sludge being dumped around the home or into a nearby water source. Alternatively, fecal sludge can be safely and simply disposed of by burying it.

This Technical Brief introduces two fecal sludge disposal options appropriate for households and communities: (1) simple pit and (2) deep row entrenchment. It gives guidance on how to locate a disposal site to minimize groundwater contamination, and discusses other measures to protect public health. As well, this Technical Brief introduces the safe disposal of urine and menstrual hygiene products.

This document provides a technical overview and is not a design manual. An experienced professional should be consulted for the design of specific disposal technologies.



CAWST focuses on the planning, design and implementation of on-site sanitation projects for low-income communities not connected to a sewer. For such communities, household or decentralized sanitation offers a hygienic and affordable solution.

CAWST's free, open content resources and schedule of international training workshops can be found at: https://resources.cawst.org and www.cawst.org/training.

Technical Brief: Fecal Sludge Disposal

2 Fecal Sludge Disposal

The simplest way to dispose of fecal sludge is to safely bury it. This method contains and controls fecal sludge to reduce the risk of contaminating water sources. Pits and trenches can be dug at the household and community level.

A goal of any disposal site is to reduce the chance of fecal sludge contaminating groundwater. There is always a risk that pathogens and other contaminants (like nitrogen) from fecal sludge will contaminate wells, boreholes and springs if they are constructed too close. Latrines should be designed and located so that the risk of groundwater contamination is minimized.

Effluent from a disposal site moves through the soil until it enters the groundwater. It then moves through the soil (or rock) with the groundwater flow. As the liquid moves through the soil, pathogens will be filtered out and naturally die-off over time. If there is not enough soil between the disposal site and the groundwater; however, then the pathogens will reach the groundwater. If the contaminated groundwater reaches a well, spring or borehole, these drinking water sources will become contaminated.

What About Disposing of Fecal Sludge in a Sewered System?

Fecal sludge should not be disposed in a sewered system. Yet, illegally dumping fecal sludge into the sewer system is common in low-income countries because it is easy to access and there are usually no other disposal options.

Fecal sludge has a higher solids content than wastewater and it can clog the sewers. As well, it can lead to severe disruptions of the wastewater treatment facility. This is because fecal sludge has different characteristics than wastewater.

See CAWST's Technical Brief: What is Fecal Sludge for more information on the differences between fecal sludge and wastewater.

(Strande, Ronteltap & Brdjanovic, 2014)

2.1 Simple Pit

Simple pits can be dug by hand. They do not have to be perfectly shaped or lined like most latrine pits. The size of the pit or trench will depend on the quantity of fecal sludge. Households may choose to dig a trench instead of a pit if they are planning to plant several trees on top of it.

The disposal site is usually located near the latrine to reduce the hassle of transportation. If the latrine was not sited properly in the first place, digging a pit near the latrine will further increase the risk of groundwater contamination.

The fecal sludge is simply dumped into the pit. It is then backfilled with 0.5 metres of soil. Do not step on or build anything on top of the full pit. The soil is unstable as the sludge settles over time. As well, build a fence or clearly mark the location. See CAWST's Latrine Construction Manual to learn more about pit excavation and safety precautions.

Technical Brief: Fecal Sludge Disposal

Disposing sludge in a simple pit

Planting a tree in the pit

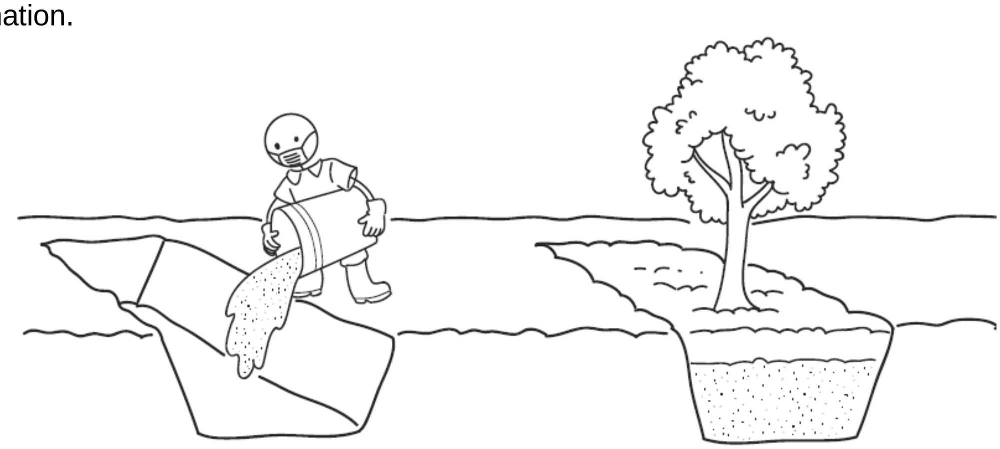
You can also plant a tree on top of the full pit. It reduces the risk of nutrients infiltrating into the groundwater and clearly marks the location of the pit. The nutrients from the sludge also help the tree to grow faster. Disposal pits can be used to reforest an area, provide a sustainable source of fresh fruit or fuel wood, and prevent people from falling into old pits. This is similar to the Arborloo latrine where the full pit is simply covered with soil and the superstructure moved to a new site. See CAWST's Fact Sheet: Arborloo for more information.

Most countries do not have legislation for using simple pits to dispose of fecal sludge.

2.2 Deep Row Entrenchment

Deep row entrenchment consists of digging deep trenches, filling them with fecal sludge, and covering them with soil. Trees are then planted on top, which can provide a source of fruit or fuel. Deep row entrenchment can be considered as both a treatment and disposal option, so it is also addressed in CAWST's Technical Brief: Fecal Sludge Treatment Technologies. Deep row entrenchment was first used for wastewater treatment and has been adapted in South Africa for fecal sludge disposal (Strande et al., 2014).

A long trench is easier to dig and fill up than a deep pit. The trench is dug manually or using an excavator. A trench is typically 0.6 metres wide and 1.2–1.5 metres deep (Still & Foxon, 2012). The length and the depth will depend on the groundwater level and volume of sludge. The trench should be lined, for example with clay, to further reduce the risk of groundwater contamination.



Disposing fecal sludge in deep trenches

The fecal sludge is simply dumped into the trench that remains open until it is full. After every dumping, a layer of soil is placed on top of the sludge to reduce smells and flies. The full trench must be backfilled with soil.

Similar to a simple pit, do not build anything afterwards on top of the full trench. The soil is unstable as the sludge settles over time. Also, do not step on the trench for the first few months, and build a fence or clearly mark the location. See CAWST's Latrine Construction Manual to learn more about excavation and safety precautions.

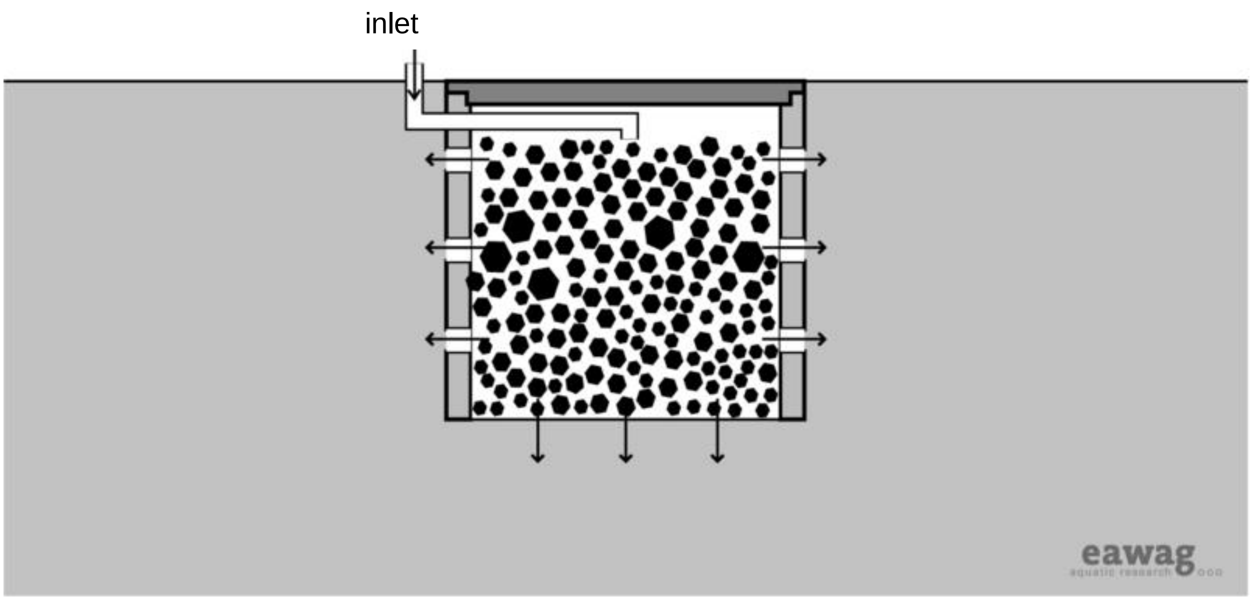
Most countries do not have legislation for deep row entrenchment to dispose of fecal sludge.

3 Urine Disposal

Urine is normally sterile (contains no pathogens) when it leaves the human body. There are only a few pathogens, such as *Schistosoma haematobium* and *Salmonella typhi*, which can be excreted in urine. However, most pathogens found in urine are caused by fecal cross-contamination. This means the urine came into contact with feces.

Source separated urine can be disposed of into the ground using a soak pit or infiltration trench. A soak pit is a dug pit that allows urine to be safely infiltrated into the ground. Trenches can be used in situations where a soak pit is unable to infiltrate the total amount of urine. In some cases, a urine diverting latrine can be connected directly to a soak pit or a trench rather than collecting the urine first in a container.

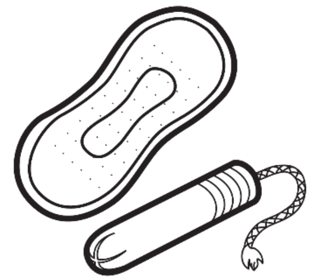
For more information, see CAWST's Technical Brief: Greywater Management and Technical Brief: Design Calculations for Soak Pits and Infiltration Trenches.



Urine can be disposed of in a soak pit (Credit: Tilley, Ulrich, Lüthi, Reymond & Zurbrügg, 2014)

4 Menstrual Hygiene Waste Disposal

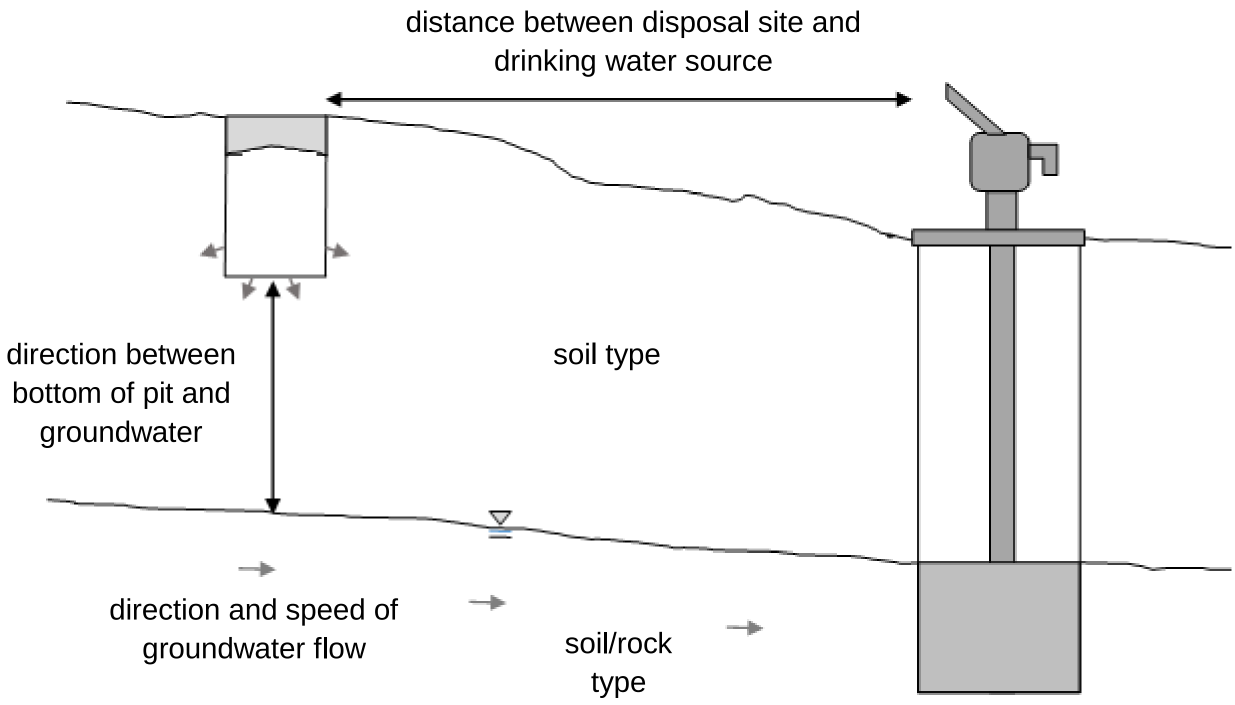
Women and girls need to use clean material to absorb or collect their menstrual blood. Sanitary pads or tampons are most commonly used and these are normally changed around four times a day during menstruation. Some sanitary pads are meant for single use and are disposed of afterwards, while others can be washed and reused. It is estimated that most women will use between 7,000 to 10,000 sanitary pads or tampons in their life. On average, a woman throws away 125 to 150 kg of sanitary pads, tampons and applicators in her lifetime (House, Mahon, & Cavill, 2012)



To manage menstruation hygienically and with dignity, it is essential that women and girls have a way to safely dispose of non-reusable sanitary products at home, in schools and in public places. Furthermore, products need to be safely disposed of to limit health risks, environmental contamination, and to stop users from throwing them in latrines. Two possible disposal options are incineration and burying. To find out more about these options, see CAWST's Technical Brief: Solid Waste Management.

5 Siting Disposal Sites

There are several technical and environmental factors that influence whether pathogens from a disposal site will contaminate a water source. One important factor is the distance between the bottom of the pit or trench and the groundwater. Another is the distance between the disposal site and the water source. The diagram below shows the factors that influence whether a disposal site may contaminate groundwater. Each of the factors in the diagram is described below in more detail.



Factors that influence groundwater contamination (Credit: Adapted from Sugden, 2006)

Technical Brief: Fecal Sludge Disposal

1. How much water is in the fecal sludge

General rule: The less liquid in the sludge, the lower the risk of contamination.

- Sludge from wet latrines (like a pour flush latrine) and sludge that has been mixed with water to make emptying easier contain large volumes of liquid. This liquid infiltrates into the ground and carries pathogens through the soil.
- Sludge from dry latrines (like a ventilated improved pit latrine) infiltrate smaller amounts of liquid into the ground, reducing the risk that pathogens will travel far through the soil and contaminate groundwater.
- Wet sludge can be dewatered before disposal.

2. Distance between the bottom of a disposal site and the highest annual groundwater level

General rule: The greater distance between the bottom of a pit or trench and the groundwater, the lower the risk of contamination. The bottom of the disposal site should be at least 2 metres above the highest annual groundwater level (Franceys, Pickford, & Reed, 1992).

- Pathogens will infiltrate directly out of the disposal site into the groundwater if the bottom of the pit is built in the groundwater table.
- The bottom of the disposal site should be at least 2 metres above the highest groundwater level (in the wet season). As the water and pathogens move through the soil over this distance, some will become trapped, and some will die before reaching the groundwater.
- Bury the fecal sludge in the dry season, if possible.

3. Soil type

General rule: The smaller the soil grain size, the lower the risk of contamination. Sludge should be buried in fine-grained soils.

- Both the soil type around/beneath the disposal site and the soil/rock type in the groundwater table should be considered.
- Coarse-grained soils, such as sand and gravel, allow groundwater and pathogens to travel further and faster. The spaces between the soil grains may be too large to trap many of the pathogens.
- Fine-grained soils, such as fine sand, silt and clay, do not let groundwater travel as fast and pathogens do not travel as fast or as far through these soils. The smaller spaces between the soil grains mean more pathogens will be trapped as they move through the soil.
- Water moves very slowly through clay. Very little liquid will infiltrate out of disposal sites built in clay soil. Groundwater will take a long time to travel any distance through clay. The water in wet fecal sludge will therefore not infiltrate very fast. This means that the disposal site will fill up faster. Sludge should be dewatered before disposing it into clay soils.

4. Distance between disposal site and drinking water source

General rule: The greater the horizontal distance between the disposal site and the drinking water source, the lower the risk of contamination. 10 metres is the minimum distance and 30 metres is often recommended for household disposal sites (Harvey, 2007). Community disposal sites should be located further away from drinking water sources than a household disposal site.

Technical Brief: Fecal Sludge Disposal

Community disposal sites receive fecal sludge from a whole community. The risk of contamination is higher. The distance will depend on various factors such as the lining of the disposal site, the soil type and national regulations.

- The greater the distance, the longer it will take for pathogens to travel. It is more likely the pathogens will die or be trapped before reaching the drinking water source.
- Minimum separation distances between the disposal site and drinking water source are recommended depending on the type of soil or rock, as shown in the following table.

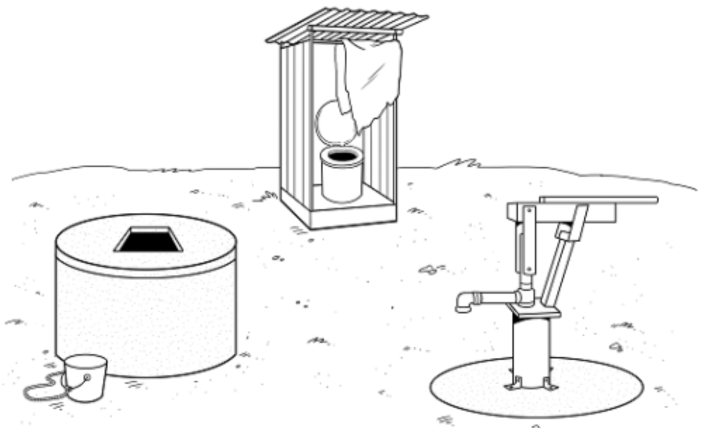
Table: Minimum Distance between a Household Disposal Site and Drinking Water Source

Soil/Rock Type	Description	Minimum Distance (metres)
Clay	Moist soil molds like plasticine, and feels sticky when wet.	10*
Silt	Moist soil forms a strong ball which smears when rubbed, but does not go shiny.	10*
Silt-sand	Moist soil forms a ball which easily deforms and feels smooth between the fingers, or still feels gritty when rubbed between the fingers.	15
Sand	Moist soil sticks together, but will not form a ball.	50
Gravel	Moist soil will not stick together.	500
Fractured rock	Rock with cracks in it through which groundwater flows.	Not recommended since water flows too fast through fractured rock

*10 metres is the minimum distance a latrine should be located from a drinking water source.

(Adapted from Harvey, 2007; Harvey, Baghri, & Reed, 2002)

A 30 metre separation distance between a household disposal site and drinking water source is often recommended. This distance is adequate in most circumstances. However, as with all general recommendations, there may be situations when a shorter distance will be acceptable or where the groundwater is contaminated despite the 30 metre separation. The soil and groundwater conditions should be assessed before siting a disposal pit or trench. The results could allow a shorter, safe separation distance or require a larger distance. Alternatives for the disposal site or the water supply should be considered, if the separation distance is not possible due to space constraints.



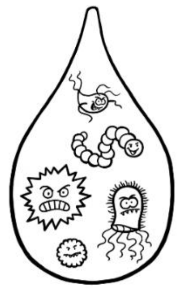
5. Direction of groundwater flow

General rule: Site disposal sites lower than the drinking water source.

- Groundwater usually flows downhill.
- In very flat areas, tests may need to be done to determine the direction of groundwater flow.
- If the disposal site is located downhill from the water source, then it is unlikely that contamination will be a problem.

(Adapted from Harvey, 2007; Sugden, 2006)

6 Monitoring Drinking Water Quality



For larger disposal sites, like deep row entrenchment, it is important to monitor the local groundwater and surface water quality. Wells, boreholes and nearby surface water bodies, especially those that are used for drinking water, should be monitored on a regular basis. This will help detect any potential contamination from the disposal site. If contamination is detected, the drinking water source should be closed off and the users should be warned. The main drinking water parameters to test for are fecal pathogens (like *Escherichia coli*) and nutrients (like nitrogen).

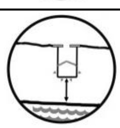
It is important to have a plan before you start doing water quality testing. Monitoring water quality can be an expensive and difficult task if it is done properly. Planning in advance and thinking through the process will save time, lower costs, and prevent surprises. Moreover, it gives a basis for the financial and human resources that will be needed to carry out your testing.

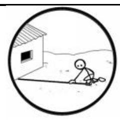
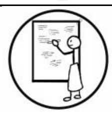
See CAWST's Introduction to Drinking Water Quality Testing resources for more information.

7 Risk Management

There are many protective measures that should be put in place when disposing of fecal sludge, to avoid spreading pathogens and to protect public health. These barriers focus on protecting people handling the fecal sludge, members of a household (particularly children), and the local community. This is often known as a multi-barrier approach.

Table: Barriers to Protect Health

Barriers to Protect Health		Action
	Use protective equipment	Wear protective equipment, such as clothing, gloves, shoes, and mask. Clean and disinfect the equipment used.
	Cover material	Cover the disposal site with at least 50 cm of soil. This creates a physical barrier between the fecal sludge, people and animals. It also limits the risk of fecal sludge resurfacing if there is heavy rainfall.
	Depth	The bottom of the disposal site should be 2 metres above the highest annual groundwater level.

Barriers to Protect Health		Action
	Site	The disposal site should be located appropriately to minimize the risk of groundwater contamination (see section on siting disposal sites). The site should also be located away from where children play.
	Restrict access	Construct a fence to keep children and animals away from the disposal site. Display warning messages.
	Treatment	Treat fecal sludge before burying it. Dewater sludge if it is particularly wet. This will reduce the amount of water infiltrating into the soil.
	Wash hands	Wash hands with soap after handling fecal sludge, tools, and equipment.
	Clean tools	Disinfect the tools used for disposal and only use them for this activity. Safely store the tools so people do not touch them or use them for another purpose.
	Train	Train workers and families on safe disposal, including hygiene practices.

8 Knowledge Gap

Knowledge on the different methods of disposing of fecal sludge is limited. The main gaps are the following:

- Research has focused on disposing of domestic wastewater sludge from sewered systems. There is not much research on fecal sludge disposal from on-site sanitation, like pit latrines and septic tanks.
- Research has focused on treatment and use of fecal sludge. However, using fecal sludge is not always an option. There needs to be more research to create recommendations on how to safely dispose of fecal sludge.
- Research is also needed on how to safely dispose of non-reusable menstrual hygiene products. Although there is a growing amount of marketing for sustainable menstrual hygiene products (for example, cups), the disposal of non-reusable products remains an issue.

9 Definitions

Dewater: The process of reducing the water content of fecal sludge. Dewatered sludge may still have a significant moisture content, but it is typically dry enough to be handled as a solid (for example, shovelled).

Excreta: Urine and feces not mixed with any flushing water.

Fecal sludge: Also called sludge. Excreta from an on-site sanitation technology (like a pit latrine or septic tank) that may also contain used water, anal cleansing materials, and solid waste.

Pathogen: An organism that causes disease.

Sewered system: Also called a sewer system, sewerage system, sewers, connected sanitation, and networked sanitation. A sanitation system that transports wastewater through a pipe network (like a simplified sewer, solids free sewer or conventional sewer) to another location for treatment, use or discharge. This includes centralized systems and decentralized wastewater treatment systems.

Treatment: Any process to inactivate pathogens, stabilize, dewater, or manage nutrients in fecal sludge.

Wastewater: Used water from any combination of domestic, industrial, commercial or agricultural activities, surface runoff (stormwater), and any sewer inflow (infiltration). Wastewater can be managed on-site or off-site. Wastewater managed off-site is often called sewage.

10 Additional Resources

CAWST Sanitation Resources. Available at: http://resources.cawst.org

- CAWST's education and training resources are available on a variety of sanitation topics including environmental sanitation; latrine design, siting and construction; fecal sludge management; and sanitation project implementation

CAWST Drinking Water Quality Testing Resources. Available at: http://resources.cawst.org

- CAWST's Drinking Water Quality Testing Manual is intended for water, sanitation and hygiene (WASH) practitioners in developing countries where there is limited access to resources. The Manual addresses characteristics of safe drinking water, planning for water quality testing, testing options (including portable field kits and laboratories), water quality parameters and test procedures, and interpreting test results.

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- This Fact Sheet describes pathogens in groundwater, factors affecting contamination of a water source by a pit latrine, ways to assess the risk of groundwater contamination, methods to reduce risk, and other issues to consider.

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Wellness through Water.... Empowering People Globally
Last Update: July 2016

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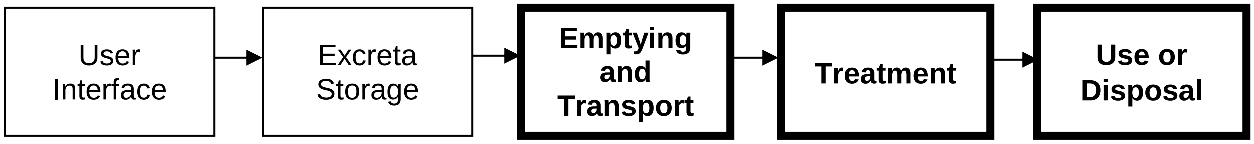
Technical Brief: Effluent Management



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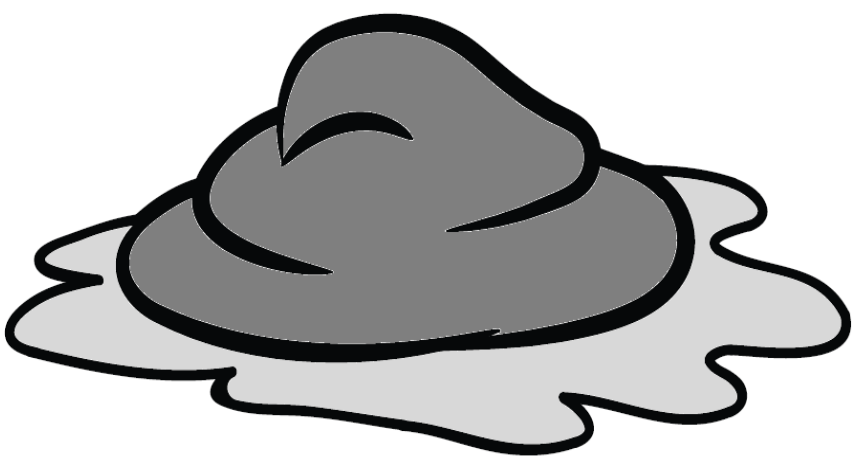


Technical Brief: Effluent Management

1 Introduction

Effluent, also known as leachate, is the general name for a liquid that is produced by an on-site sanitation technology, like a septic tank. Effluent can also be produced from fecal sludge treatment technologies.

Effluent needs to be safely managed to protect public health and prevent environmental contamination. Yet, it has traditionally received little attention and its importance is overlooked. As a result, effluent is often discharged to surface water without treatment. Effluent can also infiltrate into soil and potentially contaminate the groundwater. Or effluent that does not drain away can create pools of stagnant water that provide an ideal environment for mosquitos to breed, including mosquitos that transmit malaria.

This Technical Brief introduces the importance of safely managing effluent. It includes technologies to treat effluent, as well as ways to use or dispose of it. This Technical Brief does not address effluent from latrines that are designed to infiltrate directly into the surrounding soil (like a simple or ventilated improved pit latrine). However, it does address on-site sanitation technologies that produce effluent that needs to be managed (like a septic tank or composting latrine).

This document provides a technical overview and is not a design manual. An experienced professional should be consulted for the design of specific technologies.

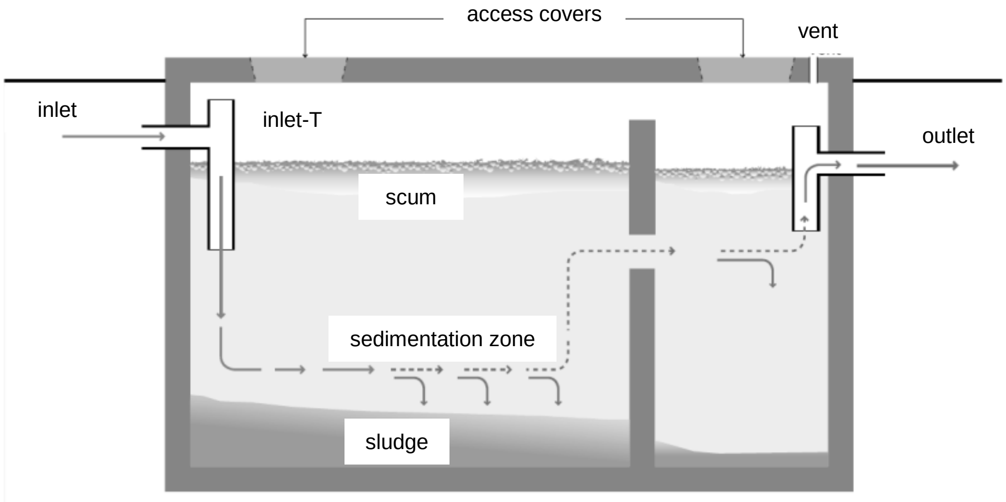
CAWST focuses on the planning, design, and implementation of on-site sanitation projects for low-income communities not connected to a sewer. For such communities, household or decentralized sanitation offers a hygienic and affordable solution.

CAWST's free, open content resources and schedule of international training workshops can be found at: https://resources.cawst.org and www.cawst.org/training.

2 Effluent Characteristics

Many on-site sanitation technologies and fecal sludge treatment technologies produce a liquid effluent. Effluent is typically high in nitrogen and pathogens. It may also contain other nutrients, heavy metals, and salts (Strande, Ronteltap & Brdjanovic, 2014).

Effluent either overflows or drains through a technology. In a septic tank, for example, solids settle to the bottom while the effluent overflows out through a pipe into a leach field or infiltration trench. Effluent in a composting latrine or bin, however, drains through to the bottom of the pile. It is often called leachate because the liquid drains (or leaches) rather than overflows.



Effluent from a septic tank overflows through an outlet (Credit: Tilley et al, 2014)

Effluent from a fecal sludge treatment technology is also different than effluent from a wastewater treatment facility. A domestic wastewater treatment facility uses a sewered system to transport excreta and flush water from toilets, as well as greywater from kitchens, laundries, and bathrooms. As a result, the effluent from a wastewater treatment facility is more dilute than effluent from fecal sludge treatment technologies. Fecal sludge is not usually mixed with large quantities of flush water and greywater, so the effluent constituents are 10-100 times more concentrated than wastewater (Strande et al., 2014).

In Haiti, leachate is called Ji Kaka. This means poop juice. This is very accurate and emphasizes the fact that leachate is not a safe liquid.

3 Treatment Technologies

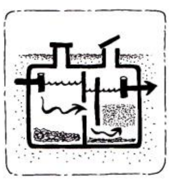
There are several technologies available to treat fecal sludge effluent. The level of pathogen inactivation and nutrient removal depends on the design and operation of the technology. The choice of treatment option usually depends on the quality of the effluent and its final use or disposal. For instance, effluent that is to be used for irrigation will need a higher level of treatment than effluent that is to be infiltrated into the ground. Even if effluent is not to be used, treating it before discharge into the environment can help to reduce water and soil contamination.

The level of research and knowledge on treatment technologies can also influence technology selection. Most fecal sludge effluent treatment technologies are transferred from wastewater treatment. There are various levels of experience in the design, operation, and maintenance specifically for faecal sludge effluent treatment.

The choice of treatment technology will also depend on national standards. Most countries have effluent quality standards, but they are not necessarily enforced in low- and middle-income countries (Strande et al., 2014).

The following table describes various fecal sludge effluent treatment technologies.

Table: Effluent Treatment Technologies

Treatment Technology	Description
 Anaerobic Filter	One or more watertight tanks are filled with filter material, like gravel, crushed rocks or bricks. A biolayer forms around the filter material over time. As effluent flows through the filter, the filter traps solid particles and the biolayer degrades organic material. Anaerobic filters are not efficient at removing nutrients and pathogens. However, worm eggs may be removed depending on the filter material used (Tilley, Ulrich, Lüthi, Reymond & Zurbrügg, 2014). The filter works without oxygen, so harmful and bad smelling gases are produced which need to be managed and vented.
 Constructed Wetlands	Also called planted gravel filters. A constructed wetland aims to copy the naturally occurring processes in wetlands. They are constructed of a bed that is lined with impermeable material and filled with coarse sand and gravel. A soil layer is usually placed on top to grow plants. As effluent slowly flows through the wetland, solid particles are trapped and adsorped, and pathogens, organic material, and nutrients are degraded by complex biochemical processes.
 Planted Drying Bed	Also called planted dewatering beds, vertical flow constructed wetlands, and drying reed beds. A planted drying bed is filled with filter material, usually gravel at the bottom and sand on top. Specific plants (macrophytes) grow in the sand filter layer. The bottom of the bed is sloped and lined with perforated pipes to drain away the liquid. Effluent is placed on the surface of the bed and the liquid flows through the sand and gravel for a period of days. The plants need to be harvested on a regular basis.
 Waste Stabilization Ponds	Waste stabilization ponds can be used to co-treat effluent with wastewater. Lined ponds are filled with effluent that is then treated by naturally occurring processes. The ponds can be used individually, or linked in a series for improved treatment. There are three types of ponds, (1) anaerobic, (2) facultative, and (3) aerobic (maturation) – all with different depths and retention times. The first pond in a series is the deepest while the last pond is the shallowest. The first pond stabilizes the effluent through anaerobic digestion. The second pond further stabilizes the sludge through both anaerobic and aerobic digestion. The shallowness of the last pond allows sunlight to penetrate through the water to inactivate pathogens.

(Strande et al., 2014; Tilley et al, 2014; Credit images: Akvo)

4 Use

As the world population continues to grow and water scarcity increases, there is more awareness on water conservation. Treated effluent can be used to irrigate home gardens or agricultural crops. This can help communities to grow more food, while at the same time conserve precious water. Effluent should be treated before it is used to reduce the risk of transmitting pathogens.

Watch the Salt!

Using effluent for irrigation will increase the salinity of the soil over the long-term. Salt can interfere with plant growth and have long-term impacts on the soil. It is recommended that salinity control practices are used, like making sure that there is enough drainage.

(Strande et al, 2014; WHO, 2006)

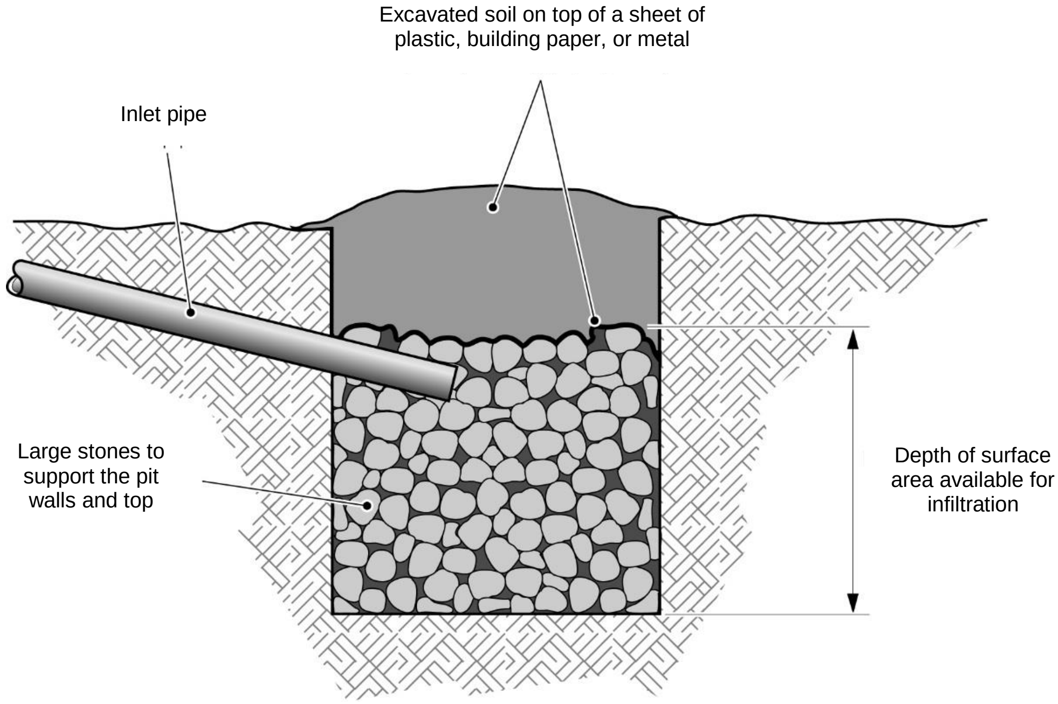
5 Disposal

Discharging effluent into a surface water body (like a river, pond, lake or sea) is the most common method of disposal, especially in urban and peri-urban areas. Effluent should be treated before discharge to protect public health and the environment. The level of treatment will depend on national standards.

There are other options to dispose effluent at the household level that are simple, low cost, and effective. Infiltrating effluent into the ground using a soak pit or infiltration trench is a simple and suitable method. This is a common disposal option for effluent produced by septic tanks.

A soak pit is a dug pit that allows used water to safely infiltrate effluent into the ground. Soak pits must be lined or filled with rocks to prevent erosion and to prevent the walls from collapsing. The size of the soak pit is based on the amount and quality of effluent entering the pit. Infiltration only happens through the side walls of the soak pit. Almost no infiltration occurs through the base of the pit because it quickly clogs with solids. It is important to design the size of the soak pit to handle peak flows of effluent, especially if the infiltration capacity of the surrounding soil is low.

Figure: Soak Pit Filled with Rocks



Soak pit filled with rocks and covered sheet and soil (Credit: Chatterton)

The simplest and quickest way to build a soak pit is to dig a pit and fill it with rocks. However, the rocks reduce the volume of water that the pit can hold and finding enough rock may be difficult in some places. Lining the soak pit walls with bricks or blocks overcomes both of these issues, but it increases the construction time, cost and difficulty.

Trenches can be used in situations where a soak pit is unable to infiltrate the total amount of effluent. This can be either because of low soil infiltration capacity, large amounts of effluent, or a combination of the two. Infiltration trenches are long shallow pits. They require more planning, space and materials than a soak pit, but create a much greater surface area for infiltration into the soil. Infiltration trenches are often used in conjunction with septic tanks.

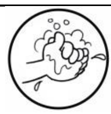
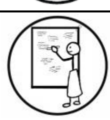
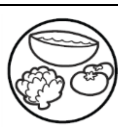
The WHO (2006) recommends locating soak pits and infiltration trenches so that they do not contaminate groundwater. See CAWST's Technical Brief: Siting Latrines for recommendations that can also be used to site soak pits and infiltration trenches.

For more information about soak pits and infiltration trenches, see CAWST's Technical Brief: Design Calculations for Soak Pits and Infiltration Trenches.

6 Risk Management

There are many protective measures that should be put in place when managing effluent. These protective measures avoid the spread of pathogens and protect human health. These barriers focus on protecting the people handling the effluent and the local community. This is often known as a multi-barrier approach. There are particular barriers depending on if the effluent is used or disposed of. The WHO guidelines for wastewater use in agriculture (2006) gives specific recommendations to minimize the health risks if the effluent is used.

Table: Barriers to Protect Health

Barriers to Protect Health			Actions
General		Treatment	Treat effluent before use and disposal.
General		Restrict access	Construct a fence to keep animals and children out of the effluent treatment, disposal. and irrigation site. Display warning messages.
General		Wash hands	Wash hands with soap after managing effluent.
General		Clean tools	Disinfect the tools used or only use them for one activity. Safely store the tools so people do not touch them or use them for another purpose.
General		Use protective equipment	Wear protective equipment, such as clothing, gloves, shoes, and mask.
General		Train	Train workers, families, and the community on the importance of effluent management and hygiene practices.
Use		Restrict crops	Only use effluent for crops that: • Are not eaten (like cotton) • Are processed (like wheat) • Are cooked (like potatoes) • Do not directly touch the ground (like bananas)
Use		Application techniques	Apply effluent on the soil and not on the plant. Avoid spraying and sprinkling irrigation.
Use		Waiting period	Wait one month after applying the effluent before harvesting crops. Pathogens continue to be inactivated once they are in the soil. Inactivation is much faster in hot and sunny climates than cold and rainy climates.
Use		Prepare food properly	Wash fruits and vegetables with safe water before eating. Wash hands with soap before cleaning and preparing food. Thoroughly cook all food and do not eat raw food.

7 Definitions

Aerobic: Biological processes that occur in the presence of oxygen.

Anaerobic digestion: The decomposition and stabilization of organic material by microorganisms without oxygen. This process produces biogas.

Degradable: Also called decomposable. A material that can be slowly broken down into simple parts.

Degradation: Also called decomposition. The transformation of dead organic material into more basic compounds and elements by biological and biochemical reactions.

Disposal: The return of waste to the environment, ideally in a way that is least harmful to public health and the environment.

Effluent: Also called leachate. Liquid that is produced from an on-site sanitation technology (like a septic tank) or fecal sludge treatment technology.

Fecal sludge: Also called sludge. Excreta from an on-site sanitation technology (like a pit latrine or septic tank) that may also contain used water, anal cleansing materials, and solid waste.

Impermeable: Also called watertight. Liquids cannot pass through.

Infiltrate: To pass into or through something. Infiltration is the process by which liquid enters the surrounding soil.

Leachate: Also called effluent. Liquid that separates from solids by gravity filtration through media (like liquid that drains from co-composting or drying beds).

Organic material: Also called organic matter. Comes from the remains of living things, such as plants and animals.

Pathogen: An organism that causes disease.

Permeable: Not watertight. Liquids can pass through.

Risk: The likelihood of a hazard causing harm to exposed populations in a specific time frame and the consequences of that harm.

Treatment: Any process to inactivate pathogens, stabilize, dewater, or manage nutrients in fecal sludge.

Wastewater: Used water from any combination of domestic, industrial, commercial or agricultural activities, surface runoff (stormwater), and any sewer inflow (infiltration). Wastewater can be managed on-site or off-site. Wastewater managed off-site is often called sewage.

8 Additional Resources

CAWST Sanitation Resources. Available at: https://resources.cawst.org

- CAWST's education and training resources are available on a variety of sanitation topics including environmental sanitation; latrine design and construction; fecal sludge management; and sanitation implementation.

Compendium of Sanitation Systems and Technologies. Tilley, E., Ulrich, L., Lüthi, C., Reymond, P. and Zurbrügg, C. (2014). 2nd Revised Edition. Eawag: Swiss Federal Institute of Aquatic Science and Technology, Dübendorf, Switzerland. Available at: www.eawag.ch/forschung/sandec/publikationen/compendium_e

- The Compendium presents the concept of sanitation systems together with detailed information about sanitation technologies for each component of sanitation systems. The document targets engineers, planners and other professionals who are familiar with sanitation technologies and processes. However, it is also a useful document for non-experts to learn about the main advantages and limitations of different technologies and the appropriateness of different systems.
- The e-Compendium, is an online, interactive version of the Compendium, complete with a tool for combining technologies into a complete sanitation system. Available at: http://ecompendium.sswm.info

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Akvo images can be retrieved at: http://akvopedia.org/wiki/Main_Page

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Technical Brief: Design Calculations for Soak Pits and Infiltration Trenches

Contents

Technical Brief: Design Calculations for Soak Pits and Infiltration Trenches

1 Introduction

This Technical Brief explains how to design soak pits and infiltration trenches used to manage domestic wastewater. A soak pit is a dug pit that allows wastewater to be safely infiltrated into the ground. Trenches can be used in situations where a soak pit is unable to infiltrate the total amount of wastewater. See CAWST's Technical Brief: Domestic Wastewater Management for further information.

The following information is provided in this Technical Brief:

- Design tables for soak pits and infiltration trenches
- Practice questions using the design tables
- Explanations of the equations used for soak pit and infiltration trench calculations
- Step-by-step sample calculations with full solutions

2 Design Basics

There are five pieces of information that must be considered to design a soak pit or infiltration trench:

1. **Infiltration area (iA):** The surface area required to infiltrate the amount of wastewater entering the pit. **IMPORTANT**: This is the surface area of just the sides of the pit. This does not include the surface area of the bottom or top of the pit. This is because the bottom clogs quickly and does not infiltrate very much water.

2. **Pit dimensions:**

    - **Length (L)** and **width (W)** for a rectangular or square pit.
    - **Diameter (d)** (the distance from one side of the circle to the opposite through the middle) for a circular pit.

3. **Soil infiltration rate (iR):** The rate at which water moves from the pit into the soil. This depends on the characteristics of the soil.

4. **Wastewater loading (Q):** The amount of wastewater entering the pit throughout a day.

5. **Pit depth (D):** How deep the pit is.

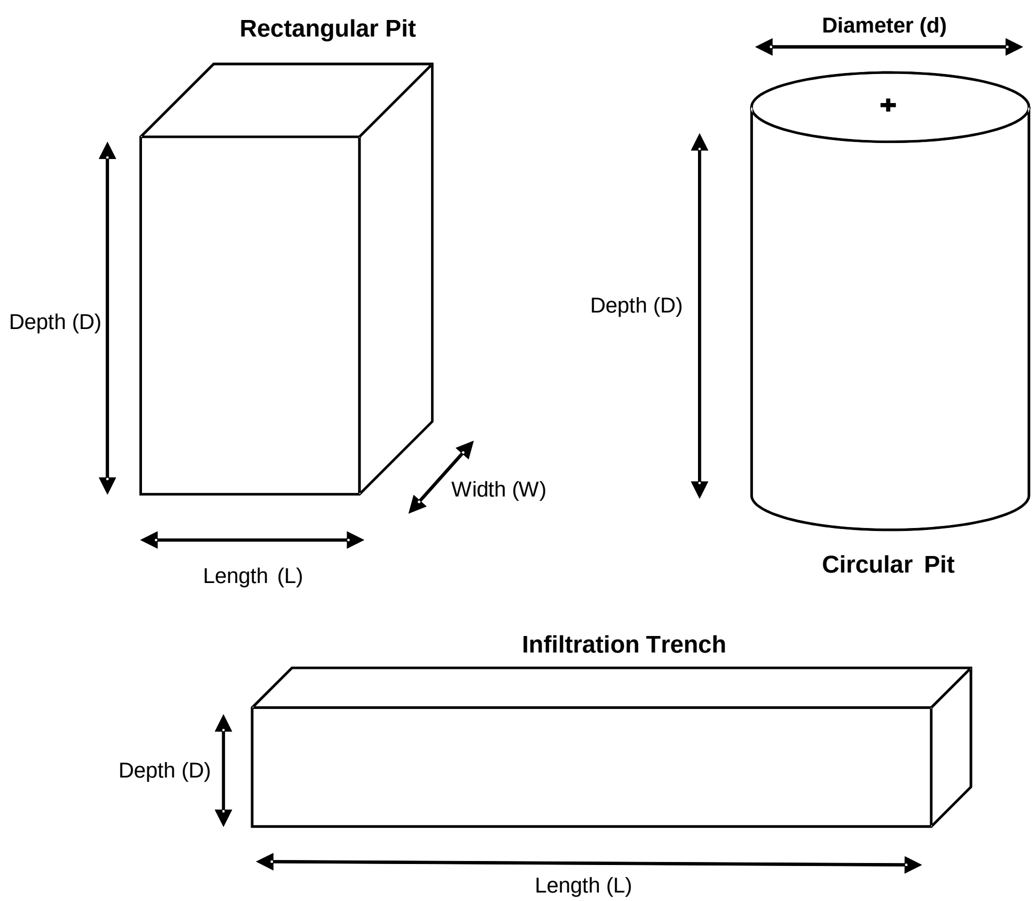
Technical Brief: Design Calculations for Soak Pits and Infiltration Trenches

3 Calculations Using Design Tables

This section provides tables that can be used to design a soak pit or infiltration trench. These tables do not cover all possible options. If none of the options are appropriate for your needs, then you will have to design your soak pit or infiltration trench by hand. Section 4 Calculations by Hand explains how to do this.

3.1 Pit Shape

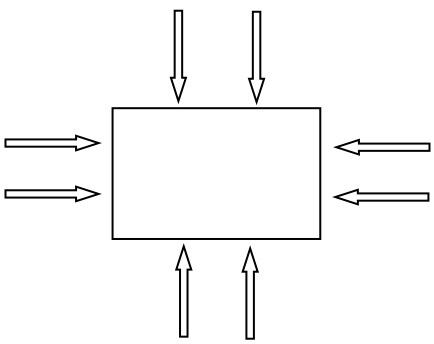
You first need to decide whether you are constructing a soak pit or infiltration trench. If building a soak pit, you then need to choose the pit shape. Soak pits can be either rectangular or circular. Infiltration trenches are normally rectangular.



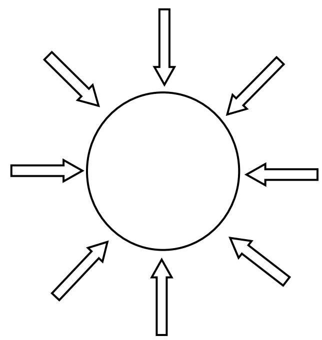
Technical Brief: Design Calculations for Soak Pits and Infiltration Trenches

When choosing the shape, remember the following:

- Circular pits are less likely to collapse because the pressure from the surrounding soil is evenly spread.
- Rectangular pits tend to collapse more often because pressure is placed on the four walls. This leaves the corners to absorb the stress.



Pressure from surrounding ground



Pressure from surrounding ground

(Lifewater, 2009)

3.2 Soil Type

You must know the type of soil to make sure you get the right design. The following table shows the different types of soil and their physical descriptions.

Types of Soil and their Physical Description

Soil Type	Physical Description
Gravel, coarse and medium sand	Moist soil will not stick together
Fine and loamy sand	Moist soil sticks together, but will not form a ball
Sandy loam and loam	Moist soil forms a ball, but still feels gritty when rubbed between the fingers
Loam, porous silt loam	Moist soil forms a ball which easily deforms and feels smooth between the fingers
Silty clay loam and clay loam	Moist soil forms a strong ball which smears when rubbed but does not go shiny
Clay*	Moist soil molds like plasticine and feels sticky when wet

(Harvey *et al*., 2002)

* Clay is not suitable for soak pits or trenches since it is difficult for the water to infiltrate the soil.

Technical Brief: Design Calculations for Soak Pits and Infiltration Trenches

3.3 Design Tables

This section provides tables that can be used to design a soak pit or infiltration trench. The tables can be used to design soak pits or infiltration trenches for inputs of 80, 120 and 160 litres of wastewater daily.

The tables were calculated assuming that the pit or trench will be lined and not filled with rocks. You may want to slightly increase the dimensions of your pit or trench if you will be filling it with rocks instead of lining it.

Practical Considerations

1. A pit deeper than 1.2 metres should be supported by lining or shoring (a temporary support structure) while digging. This will help to prevent it from collapsing on the person digging.
2. The bottom of the pit should be at least 2 metres above the highest annual groundwater level.
3. Infiltration trenches are long, narrow (about the width of a shovel), and shallow. They usually require more space and materials, but can infiltrate a larger amount of water than a soak pit.

Important Information for Soak Pit Tables

The tables are calculated assuming a concrete slab will be placed as a cover. If your soak pit will be buried underground, you will need space for cover, drainage, and backfill. For buried pits, add at least 0.2 metres onto the value found in the table.

Technical Brief: Design Calculations for Soak Pits and Infiltration Trenches

Soak Pit Design for 1 metre Diameter (Circular) or 1 x 1 metre Square (Rectangular)

Soil Type	Pit Depth (metres)					
	80 litres Daily		120 litres Daily		160 litres Daily	
	Circle	Square	Circle	Square	Circle	Square
Gravel, coarse and medium sand	0.5	0.4	0.8	0.6	1.0	0.8
Fine and loamy sand	0.8	0.6	1.2	0.9	1.5	1.2
Sandy loam and loam	1.1	0.8	1.6	1.3	2.1	1.7
Loam, porous silt loam	1.4	1.1	2.1	1.7	2.8	2.2
Silty clay loam and clay loam	3.2	2.5	4.8*	3.8*	6.4*	5.0*

Soak Pit Design for 1.2 metre Diameter (Circular) or 1.2 x 1.2 metre Square (Rectangular)

Soil Type	Pit Depth (metres)					
	80 litres Daily		120 litres Daily		160 litres Daily	
	Circle	Square	Circle	Square	Circle	Square
Gravel, coarse and medium sand	0.4	0.3	0.6	0.5	0.8	0.7
Fine and loamy sand	0.6	0.5	1.0	0.8	1.3	1.0
Sandy loam and loam	0.9	0.7	1.3	1.0	1.8	1.4
Loam, porous silt loam	1.2	0.9	1.8	1.4	2.4	1.9
Silty clay loam and clay loam	2.7	2.1	4.0	3.1	5.3	4.2

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Technical Brief: Design Calculations for Soak Pits and Infiltration Trenches

Important Information for Infiltration Trench Tables

These tables were calculated for a 0.5 metre depth and a 1.0 metre depth. When you actually go to build the trench, dig at least 0.2 metres deeper so that there is space for soil cover. For example, if you want a trench depth of 0.5 metres, then you must dig 0.7 metres deep. For a 1.0 metre depth, you must dig 1.2 metres deep.

Infiltration Trench Design for 0.5 metre Deep Trench
(not including depth of cover)

Soil Type	Trench Length (metres)		
	80 litres Daily	120 litres Daily	160 litres Daily
Gravel, coarse and medium sand	1.6	2.4	3.2
Fine and loamy sand	2.4	3.6	4.8
Sandy loam and loam	3.3	5.0	6.7
Loam, porous silt loam	4.4	6.7	8.9
Silty clay loam and clay loam	10.0	15.0	20.0

Infiltration Trench Design for a 1.0 metre Deep Trench
(not including depth of cover)

Soil Type	Trench Length (metres)		
	80 litres Daily	120 litres Daily	160 litres Daily
Gravel, coarse and medium sand	0.8	1.2	1.6
Fine and loamy sand	1.2	1.8	2.4
Sandy loam and loam	1.7	2.5	3.3
Loam, porous silt loam	2.2	3.3	4.4
Silty clay loam and clay loam	5.0	7.5	10.0

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3.4 Practice Questions

Use the design tables in Section 3.3 to answer the following questions. Solutions are found at the end of this section.

Question 1

- A family wants to build a rectangular soak pit
- They need to dispose of 80 litres of wastewater each day
- They want to make it 1 metre by 1 metre
- They are digging in sandy loam

How deep should their pit be?

Question 2

- A family wants to build a circular soak pit
- They need to dispose of 120 litres of wastewater each day
- They want to make it with a 1.2 metre diameter
- They are digging in fine and loamy sand

How deep should their pit be?

Question 3

- A family wants to build an infiltration trench.
- They need to dispose of 80 litres of wastewater each day
- The depth of the trench walls is 0.5 metres
- They are digging in sandy loam

How long should their trench be? How deep do they have to dig to account for 0.2 metres of cover?

Answers to Practice Questions:

1. Pit depth = 0.8 metres
2. Pit depth = 1.0 metres
3. Trench depth = 3.3 metres, Dig = 3.5 metres

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4 Calculations by Hand

This section will explain the equations that are used to design soak pits and infiltration trenches. It will then lead you through sample and practice questions.

There are two ways to calculate the infiltration area: 1) using the dimensions of the pit or trench, or 2) based on how much wastewater will enter the pit or trench.

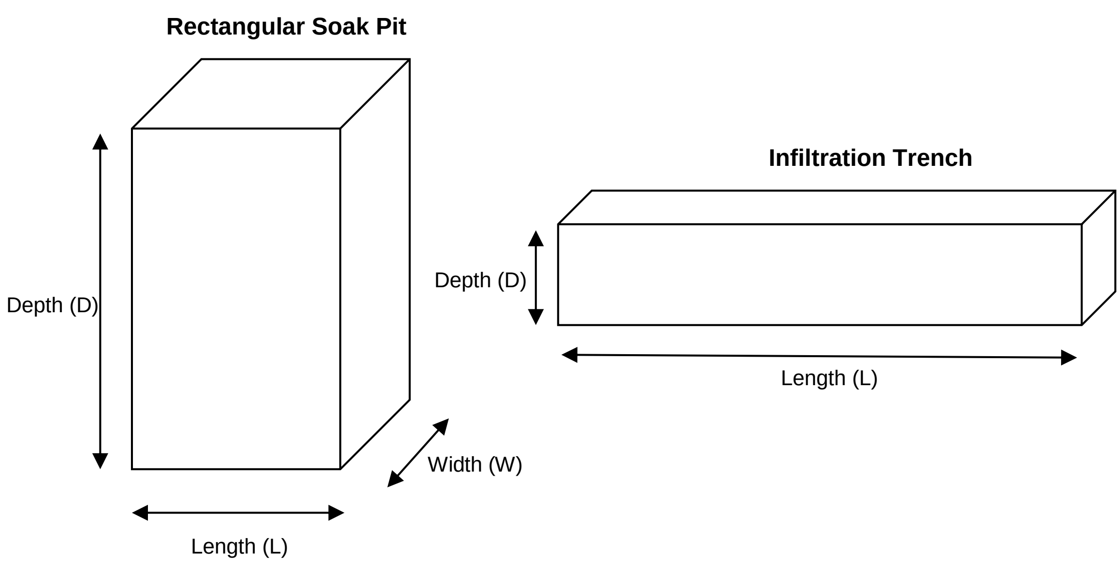
4.1 Calculating Infiltration Area for Pits and Trenches Based on Dimensions

We will start with the pit shapes and the equations that are needed to figure out infiltration area.

4.1.1 Rectangular Pit

The infiltration area for a rectangular pit can be calculated from the three pit dimensions:

- **Depth**
- **Length**
- **Width**



A rectangular shape is made of three sets of rectangles that have different dimensions.

1. **Top and bottom** are the same
2. **Front and back** are the same
3. **Side and side** are the same

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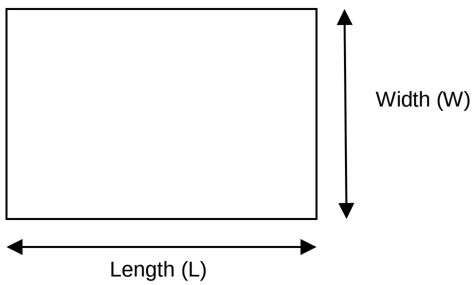
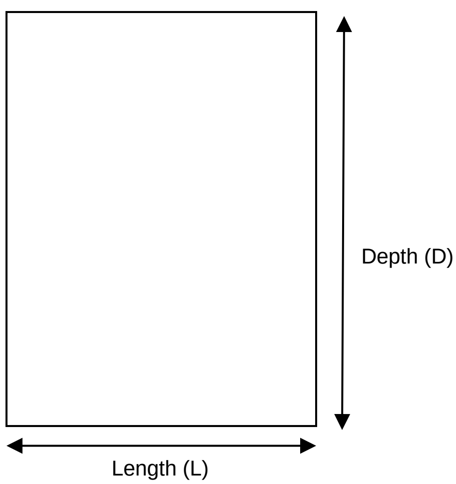


Top and Bottom

This is the shape that you see when you look at the pit from above.

The length and width of the pit are most likely determined by the size of slab you have or can build.

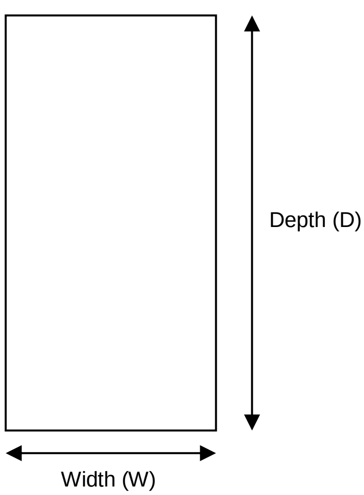


Front and Back

You create the depth as you dig your pit.

The *front and back* rectangle shares the length dimension of the *top and bottom* rectangle.

The dimensions of this rectangle are length (L) and depth (D).



Side and Side

The *side and side* rectangle has the same depth (D) as the *front and back* rectangles.

It also has the same width (W) as the *top and bottom* rectangles.

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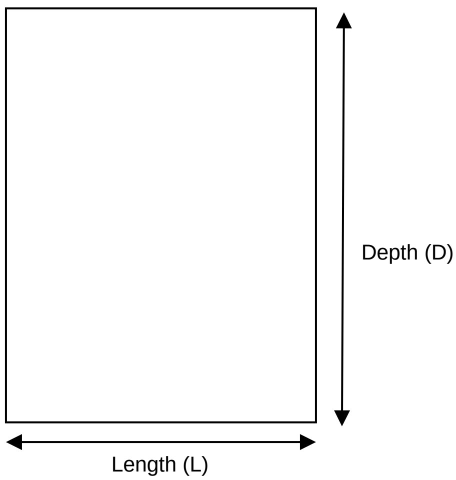
Infiltration Area

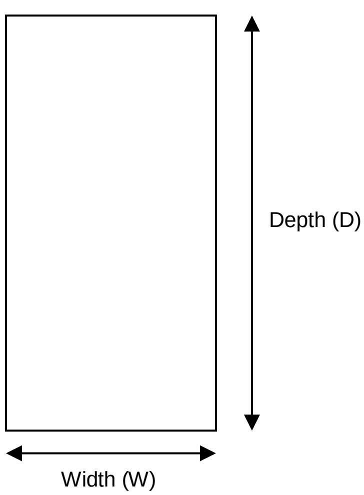
Area of Front and Back Rectangles



$$Area = Length \times Depth$$
$$A = L \times D$$

- Length and depth are measured in metres (m)
- Surface area is measured in square metres (m^2)

Area of Side and Side Rectangles



$$Area = Width \times Depth$$
$$A = W \times D$$

- The side and side rectangle has the same depth (D) as the front and back rectangles.

Technical Brief: Design Calculations for Soak Pits and Infiltration Trenches

Important Information

In soak pit calculations, *infiltration area* refers to the total area of all the **sides** of the rectangle (this does not include the top and bottom because the bottom clogs so quickly).

In infiltration trench calculations, *infiltration area* refers to the total area of only the two long sides (it does not include the top and bottom because the bottom clogs quickly or the two ends (side and side) because that area is so small). In an infiltration trench the length will always be larger than the depth.

Soak Pit Infiltration Area

The infiltration area of the pit is the total area of the front, back, and two sides.

$$\text{Infiltration area} = \text{Front area} + \text{Back area} + \text{Side area} + \text{Side area}$$

$$iA = (L \times D) + (L \times D) + (W \times D) + (W \times D)$$

$$iA = 2 \times (L \times D) + 2 \times (L \times D)$$

$$\boxed{iA = 2 \times D \times (L + W)}$$

Infiltration Trench Infiltration Area

The infiltration area of the trench is the total area of the front and back.

$$\text{Infiltration area} = \text{Front area} + \text{Back area}$$

$$\text{iA} = (\text{L} \times \text{D}) + (\text{L} \times \text{D})$$

$$\boxed{\text{iA} = 2 \times \text{L} \times \text{D}}$$

This equation can be rearranged to find length.

$$\boxed{\text{L} = \frac{\text{iA}}{2 \times \text{D}}}$$

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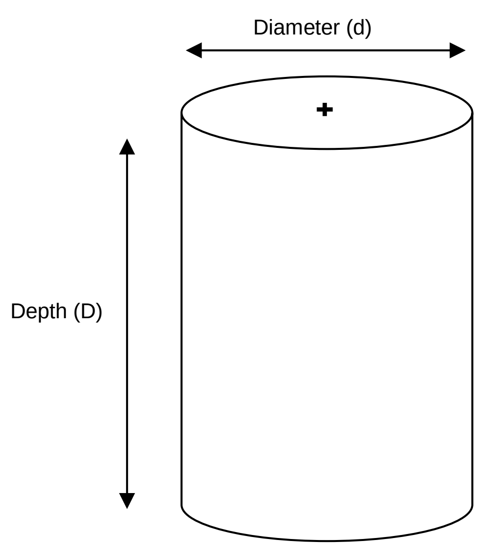
Practical Considerations

Usually, infiltration trenches are no deeper than about 1 metre. This is because it is easier to dig a long shallow trench rather than a deep trench. A soak pit may better meet your needs if you are going much deeper than 1 meter.

Infiltration trenches require a soil cover that is normally at least 0.2 metres. Remember to add this to your total depth after doing your calculations. This is how deep you will actually dig.

4.1.2 Circular Pit

Infiltration area for a circular pit can be calculated from the two pit dimensions: **depth and diameter** (the distance across the circle through the middle)**.**



Circular Pit

Important Information

In soak pit calculations, *infiltration area* refers to the total side area of a circular pit (this does not include the top and bottom). This is because the bottom will clog very quickly and not infiltrate much water.

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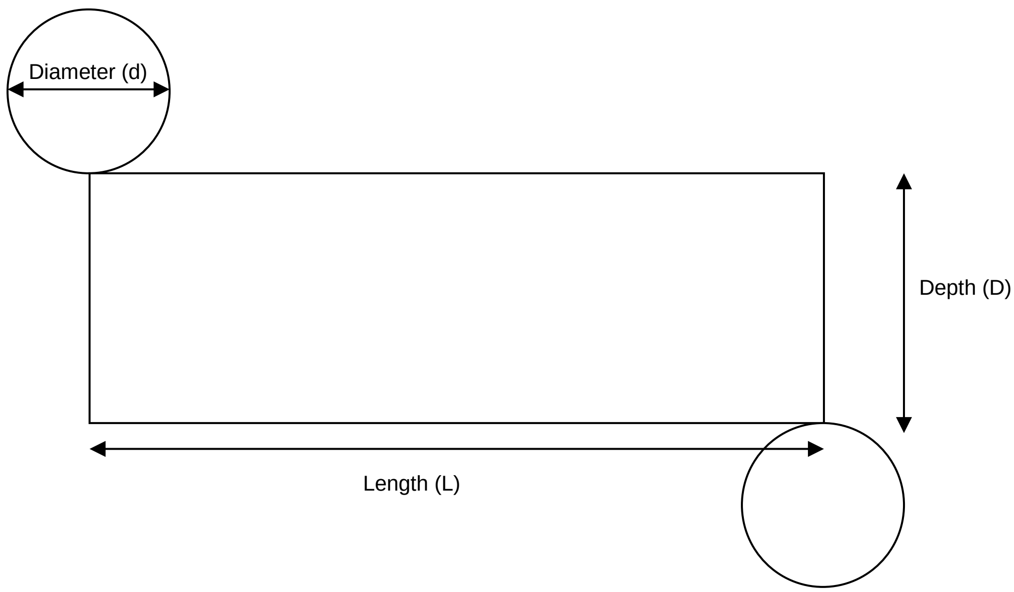
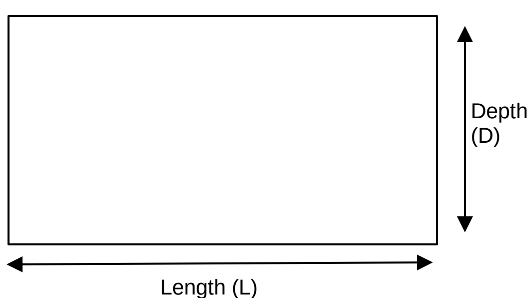
A circular pit shape is called a cylinder. It is made up of two identical circles that are the top and the bottom, and a rectangle that wraps around them. If you were to unroll a cylinder and lay it flat on the ground it would look like this:



The rectangular part of the unrolled cylinder is the sides of the pit. Therefore the area of this rectangle is the **infiltration area**.

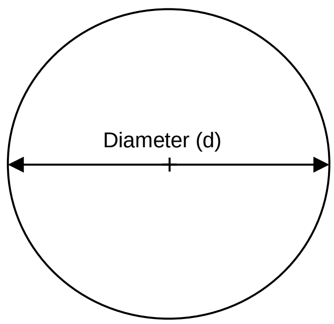


$$\text{Infiltration Area} = \text{Length} \times \text{Depth}$$
$$iA = L \times D$$

- Length and depth are measured in metres (m)
- Surface area is measured in square metres (m^2)

Technical Brief: Design Calculations for Soak Pits and Infiltration Trenches

When designing a circular pit we do not know the length of the rectangle. What we do know is that the length of the rectangle is equal to the distance around one of the circles, also known as circumference of a circle. We can figure out the circumference and therefore the length based on the diameter of the pit.



$$\text{Length} = \text{Diameter} \times 3.14$$
$$L = d \times 3.14$$

- Diameter is measured in metres (m)
- Length is measured in metres (m)
- 3.14 is a rounded value for the ratio pi (π)

Therefore, the equation for the **infiltration area** of a circular pit is:

$$\text{Infiltration Area} = \text{Length} \times \text{Depth}$$
$$iA = L \times D$$
$$iA = d \times 3.14 \times D$$

Technical Brief: Design Calculations for Soak Pits and Infiltration Trenches

4.2 Calculating Infiltration Area Based on Usage

The following equation tells us how much infiltration area is needed based on how much water will be entering the pit.

Wastewater loading is how much water is entering the pit daily.

- Soil infiltration rate is how fast the water entering the pit can move through the soil.
- This rate is based on the type of soil.

$$\text{Infiltration area} = \frac{\text{Wastewater loading}}{\text{Soil infiltration rate}}$$

$$iA = \frac{Q}{iR}$$

The following table gives soil infiltration rates based on the type of soil where the pit will be dug.

Typical Soil Infiltration Rates According to Soil Type

Soil Type	Physical Description	Infiltration Rate of Wastewater ($L/m^2/day$)
Gravel, coarse and medium sand	Moist soil will not stick together	50
Fine and loamy sand	Moist soil sticks together, but will not form a ball	33
Sandy loam and loam	Moist soil forms a ball, but still feels gritty when rubbed between the fingers	24
Loam, porous silt loam	Moist soil forms a ball which easily deforms and feels smooth between the fingers	18
Silty clay loam and clay loam	Moist soil forms a strong ball which smears when rubbed but does not go shiny	8
Clay*	Moist soil molds like plasticine and feels sticky when wet	Unsuitable for soak pits or infiltration trenches

(Harvey *et al*., 2002)

An infiltration rate test can be done if you cannot determine the soil type and infiltration rate from the above table. This test measures how much water infiltrates into the ground in a specific period of time. For accurate results, the test should be done at the same depth as the base of the planned pit or trench.

Method

1. Force an open steel or plastic cylinder or tube (approximately 30 cm diameter) into the ground.
2. Insert a ruler or other measure marked in millimetres into the tube.
3. Fill the tube with clean water and measure the fall in water level over time. For example measurements can be taken at 5, 10, 20, 30 and 60 minutes.
4. Determine the infiltration rate for each time period in mm/day using the calculation below:

$$\text{Infiltration rate (mm/day or L/m}^2\text{/day)} = \frac{\text{Fall in water level (mm)}}{\text{Time (min)}} \times 1440\ \text{(min/ day)}$$

NOTE: mm/day and L/m^2/day are the same unit, just expressed differently. Infiltration rate tables often use L/m^2/day.

5. Calculate the average using the calculation below:

$$\textit{Average Infiltration rate (mm/day)} = \frac{\textit{Sum of infiltration rates}}{\textit{Number of infiltration rates}}$$

6. Estimate the infiltration rate for wastewater. To do this, use the following Table: Typical Infiltration Rates Comparing Clean Water and Wastewater, and find the range that your rate fits in under the ‘clean water’ column. From this value you can see the corresponding wastewater infiltration rate for that soil type.

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Typical Infiltration Rates Comparing Clean Water and Wastewater

Soil Type	Description	Infiltration Rate L/m^2/day	
		Clean Water	**Wastewater**
Gravel, coarse and medium sand	Moist soil will not stick together	1,500-2,400	50
Fine and loamy sand	Moist soil sticks together but will not form a ball	720-1,500	33
Sandy loam and loam	Moist soil forms a ball but still feels gritty when rubbed between the fingers	480-720	24
Loam, porous silt loam	Moist soil forms a ball which easily deforms and feels smooth between the fingers	240-480	18
Silty clay loam and clay loam	Moist soil forms a strong ball which smears when rubbed but does not go shiny	120-240	8
Clay	Moist soil molds like plasticine and feels sticky when wet	24-120	Unsuitable for soak pits or trenches

(Harvey *et al*., 2002)

The infiltration rates for wastewater given in the table above are much lower than those for clean water. This is because the spaces between the soil particles become clogged by suspended particles and organic matter in the wastewater. Also, these rates are very likely to decrease over time.

Technical Brief: Design Calculations for Soak Pits and Infiltration Trenches

4.3 Summary of Equations

Use the information in this section as a reference and to help work through the example questions.

Summary of Equations to Design Soak Pits and Infiltration Trenches

Dimension	Formula	Variables
Geometric Infiltration Area: Rectangular Soak Pit	$iA = 2 \times D \times (L + W)$	iA: Infiltration area (m^2) D: Depth (m) L: Length (m) W: Width (m)
Geometric Infiltration Area: Circular Soak Pit	$iA = d \times 3.14 \times D$	iA: Infiltration area (m^2) d: Diameter (m) D: Depth (m)
Geometric Infiltration Area: Infiltration Trench	$iA = 2 \times L \times D$	iA: Infiltration area (m^2) D: Depth (m) L: Length (m)
Usage Infiltration Area	$iA = \frac{Q}{iR}$	iA: Infiltration area (m^2) iR: Infiltration rate (l/m^2/day) Q: Wastewater loading (L/day)
Infiltration Trench Length	$V = D \times A$	D: Depth (m) A: Area (m^2)

Technical Brief: Design Calculations for Soak Pits and Infiltration Trenches

4.4 Example Questions

The following are examples with the solutions to help you practice designing soak pits and infiltration trenches using equations.

4.4.1 Rectangular Soak Pit Calculation – Finding Depth

- A family needs to dispose of 100 litres of wastewater per day
- They want the soak pit to have a length of 1.2 metres and a width of 1.0 metre
- They are digging in sandy loam

How deep should their soak pit be?

Solution

Step 1: Known information – Write down the variables and their values. Identify the variable that you need to solve for.

Shape = Rectangular

Wastewater Loading $\mathbf{Q} = 100$ (litres/day)

Length $\mathbf{L} = 1.2$ metres

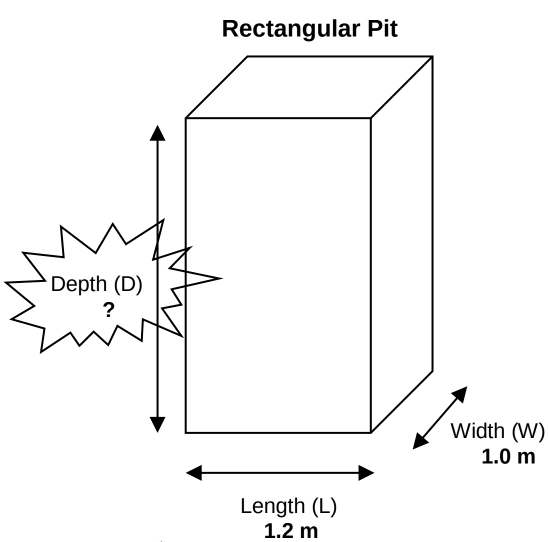
Width $\mathbf{W} = 1.0$ metre

Infiltration Rate $\mathbf{iR} = 24$ (litres/metres^2/day)

Depth $\mathbf{D} = ?$

We are using an infiltration rate of 24 (L/m^2/day) because we are digging in sandy loam.

Step 2: Draw and Label Your Diagram – Draw a diagram of the pit and label all dimensions.



We are trying to find the depth (D) of the pit.

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Step 3: Formulas – Write down the formula for the variable you are trying to solve for. Check if you have the value for each variable in it. If the values are not given, then find an equation to give you the missing value of the variable you want. Be sure that you are using the formula for the right shape.

$$D = \frac{iA}{2 \times (L + W)} \rightarrow iA = ?,\quad L = 1.2m,\quad W = 1.0m$$

- *The first equation gives the depth but we don't know the value of iA (infiltration area).*

$$iA = \frac{Q}{iR} \rightarrow Q = 100(L/day),\quad iR = 24(L/m^2/day)$$

- *The second equation gives the value for iA (infiltration area).*

Step 4: Fill in the formula that you know the value of all the variables for.

$$iA = \frac{Q}{iR}$$

$$iA = \frac{100(L/day)}{24(L/m^2/day)}$$

$$\boxed{iA = 4.2m^2}$$

We are finding the value for iA (infiltration area) first because we know the values for both Q (wastewater loading) and iR (soil infiltration rate).

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Step 5: Fill in the formula that you know the value of all the variables for.

$$D = \frac{iA}{2 \times (L + W)}$$

From the previous equation we now know the value of iA. We can now solve for D.

$$D = \frac{4.2m^2}{2 \times (1.2m + 1.0m)}$$

$$D = \frac{4.2m^2}{2 \times 2.2m}$$

$$D = \frac{4.2m^2}{4.4m}$$

$$\boxed{D = 1.0m}$$

- *Fill in all the values for the variables.*
- *Do the addition inside the brackets first.*
- *Do the multiplication.*
- *Do the division.*

Step 6: Write out the answer.

The depth must be 1.0 metre for the pit to infiltrate 100 litres of wastewater each day. This is assuming the pit has a slab for a cover. If soil will be used for cover, then at least 0.2 metres must be added to the depth.

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4.4.2 Circular Soak Pit Calculation – Finding Depth

- A family needs to dispose of 100 litres of wastewater per day
- They want the soak pit to have a diameter of 1.3 metres
- They are digging in porous silt loam

How deep should their soak pit be?

Solution

Step 1: Known information – Write down the variables and their values. Identify the variable that you need to solve.

$\text{Shape} = \text{circular}$

$\text{Wastewater Loading } \mathbf{Q} = 100 \text{ (litres/day)}$

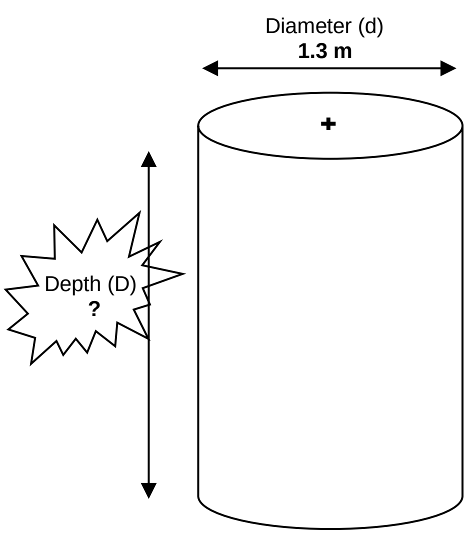
$\text{Diameter } \mathbf{d} = 1.3 \text{ metres}$

$\text{Infiltration Rate } \mathbf{iR} = 18 \text{ (litres/metres}^2 \text{ / day)}$

$\text{Depth } \mathbf{D} = ?$

We are using an infiltration rate of 18 (L/m^2/day) because we are digging in porous silt loam.

Step 2: Draw and Label Your Diagram – Draw a diagram of the pit and label all dimensions.



Circular Pit

We are trying to find the depth (D) of the pit.

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Step 3: Formulas – Write down the formula for the variable you are trying to solve for. Check if you have the value for each variable in it. If the values are not given, then find an equation to give you the missing value of the variable you want. Be sure that you are using the formula for the right shape.

$$D = \frac{iA}{3.14 \times d} \longrightarrow iA = ?,\quad d = 1.3m$$

$$iA = \frac{Q}{iR} \longrightarrow Q = 100\,(L/day),\quad iR = 18\,(L/m^2/day)$$

- *The first equation gives the depth but we don't know the value of iA (infiltration area).*
- *The second equation gives the value for iA (infiltration area).*

Step 4: Fill in the formula that you know the value of all the variables for.

$$iA = \frac{Q}{iR}$$

$$iA = \frac{100(L/day)}{18(L/m^2/day)}$$

$$\boxed{iA = 5.6m^2}$$

We are finding the value for iA (infiltration area) first because we know the values for both Q (wastewater loading) and iR (soil infiltration rate).

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Step 5: Fill in the formula that you know the value of all the variables for.

$$D = \frac{iA}{3.14 \times d}$$

- *From the previous equation we now know the value of iA. We can now solve for D.*

$$D = \frac{5.6m^2}{3.14 \times 1.3m}$$

$$D = \frac{5.6m^2}{4.1m}$$

$$\boxed{D = 1.4m}$$

- *Fill in all the values for the variables.*
- *Do the multiplication first.*
- *Do the division.*

Step 6: Write out the answer.

The depth must be 1.4 metres for the pit to infiltrate 100 litres of wastewater each day. This is assuming the pit has a slab for a cover. If soil will be used for cover, then at least 0.2 metres must be added to the depth.

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4.4.3 Infiltration Trench – Finding Length

- A family needs to dispose of 80 litres of wastewater per day
- They want the walls of their infiltration trench to be 0.5 metres deep
- They are digging in sandy loam

How long should their trench pit be?

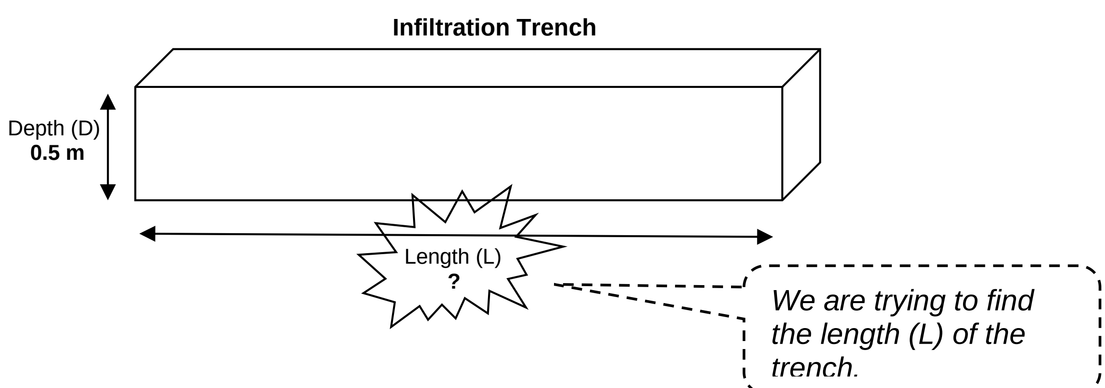
Solution

Step 1: Known information – Write down the variables and their values. Identify the variable that you need to solve for.

$$\text{Amount of Wastewater to be Infiltrated } \mathbf{Q} = 80 \text{ (litres/day)}$$
$$\text{Infiltration Rate } \mathbf{iR} = 24 \text{ (litres/ metres}^2\text{/day)}$$
$$\text{Depth } \mathbf{D} = 0.5 \text{ metres}$$
$$\text{Lenght } \mathbf{L} = ?$$

We are using an infiltration rate of 24 (L/m^2/day) because we are digging in sandy loam.

Step 2: Draw and Label Your Diagram – Draw a diagram of the pit and label all dimensions.



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Step 3: Formulas – Write down the formula for the variable you are trying to solve for. Check if you have the value for each variable in it. If the values are not given, then find an equation to give you the missing value of the variable you want. Be sure that you are using the formula for the right shape.

$$L = \frac{iA}{2 \times D} \longrightarrow iA = ?,\quad D = 0.5m$$

$$iA = \frac{Q}{iR} \longrightarrow Q = 80(L/day),\quad iR = 24(L/m^2/day)$$

- *The first equation gives the length but we don't know the value of iA (infiltration area).*
- *The second equation gives the value for iA (infiltration area).*

Step 4: Fill in the formula that you know the value of all the variables for.

$$iA = \frac{Q}{iR}$$

$$iA = \frac{80(L/day)}{24(L/m^2/day)}$$

$$\boxed{iA = 3.33m^2}$$

We are finding the value for iA (infiltration area) first because we know the values for both Q (wastewater loading) and iR (soil infiltration rate).

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Step 5: Fill in the formula that you know the value of all the variables for.

$$L = \frac{iA}{2 \times D}$$

From the previous equation we now know the value of iA. We can now solve for L.

$$L = \frac{3.33m^2}{2 \times 0.5m}$$

$$L = \frac{3.33m^2}{1.0m}$$

$$\boxed{L = 3.33m}$$

- *Fill in all the values for the variables.*
- *Do the multiplication.*
- *Do the division.*

Step 6: Write out the answer.

The length must be 3.33 metres for the pit to infiltrate 80 litres of wastewater each day. A soil cover at least 0.2 metres must be added to the depth.

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5 Additional Resources

CAWST (2015). Technical Brief: Domestic Wastewater Management. CAWST, Calgary, Canada. Available at: www.cawst.org/resources

- This Technical Brief discusses how to safely and properly dispose domestic wastewater, including greywater and overflow water. Grease traps, soak pits and infiltration trenches are explained.

6 References

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