WATER GLOBAL PRACTICE

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Improving Sanitation in Cold Regions

Catalog of Technical Options for Household-Level Sanitation

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WORLD BANK GROUP

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Introduction

Globally, 2.5 billion people lack access to improved sanitation. Improving sanitation is a challenge around the world; cold climates add to that challenge.

The objective of this Catalog is to identify suitable technological options for delivering sustainable improved sanitation in cold regions where the population is not served by piped water supply and sewer networks.

For this report, *sanitation* refers to the management of human excreta—that is, urine and feces. An *improved* sanitation facility protects and promotes human health by providing a clean environment and breaking the cycle of disease, and promoting sustainability by being economically viable, socially acceptable, and technically and institutionally appropriate.

There is no agreed-on definition of what constitutes a cold region. For the purposes of this Catalog, a *cold region* is defined as a region where the mean monthly temperature is below 1°C for one month or more per year. There are places where the soil freezes and thaws seasonally on every continent, including more than 50 percent of the Northern Hemisphere's land surface (National Snow and Ice Data Center 2016).

No matter how cold region is defined, sanitation for large numbers of people is affected by cold temperatures. In 2015, more than 2.5 billion people lived in countries where the average monthly temperature has historically been below 1°C for at least one month of the year. Of these, 1.5 billion lived in countries where the average monthly temperature was below -5°C for at least three months of the year.[1]

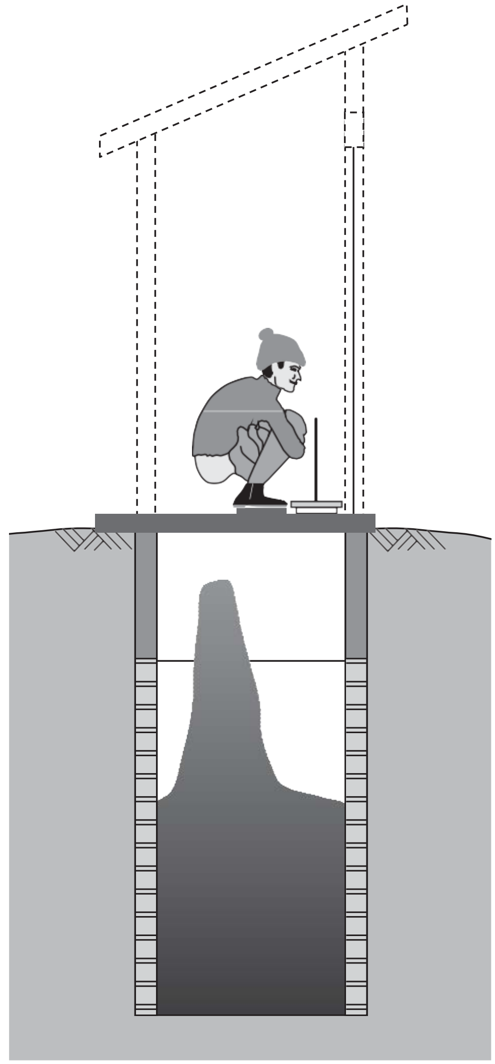

Figure ES.1.1 Pit Latrine Use in the Cold Season

Source: Adapted from WEDC, Loughborough University.

Surprisingly little attention has been paid to sanitation for cold regions—especially low-cost sanitation. Yet technical problems caused by the very low temperatures add significantly to the cost and complexity of designing, building, operating, and maintaining water and sanitation infrastructure.

Moreover, many of the communities and countries affected by very cold climates are remote, poor, and vulnerable, and they often find it difficult to pay for complex water and sanitation infrastructure. Figure ES.1 shows frozen excreta in a pit latrine, illustrating just one of the potential effects of cold on sanitation.

Effects of Cold Temperatures on Sanitation

The effects of cold temperatures on sanitation vary, so each of the options presented in this Catalog should be evaluated and tested in local conditions. Freezing air temperatures affect above-ground infrastructure, whereas freezing soil affects in-ground installations from pipes to pits. The length and severity of the cold season, the amount of snowfall, hydrogeological conditions, building density, and vegetative cover are among the main factors affecting the depth and duration of soil freezing.

Cold temperatures affect the processes that take place in sanitation systems, which in turn affect requirements for design, construction, and operation. Some of the main effects include the following:

- ✓ Many treatment processes critical to protecting public health and the environment from pollution are less effective in cold temperatures—or do not work at all.
- ✓ Frozen saturated soil is impermeable, so any systems that depend on infiltration of the liquid portion of the waste into the soil will be negatively affected.
- ✓ The waste in the pipes, pits, tanks, vaults, and other containers can freeze, thus blocking and potentially damaging them. Thawing them can be very difficult during the cold season.
- ✓ Wastewater can freeze and block drainage canals, or it can freeze and create an icy hazard on land surfaces. When the wastewater thaws, it can pollute the surrounding area.
- ✓ Soil movement caused by freezing and thawing of the water in the soil pores can damage sanitation facilities and infrastructure.
- ✓ Construction is also affected. For instance, digging in frozen soil is difficult, and concrete that freezes while hydrating is likely to be weak.
- ✓ Structures may need to be designed and built to resist loads from snow and ice.

The choice of feasible, cost-effective, proven systems for cold regions in developing countries that adequately protect human health and the environment is limited. Many designs and processes that work well in tropical or temperate climates must be modified to work in cold climates. The required modifications can be prohibitively costly or complex, if they work at all.

Recommended Options

Making suitable technical options available to consumers will not lead to widespread or sustained improvements in sanitation without appropriate institutional, financial, or regulatory frameworks. Regulations, financial arrangements, institutional support, policies, strategies, plans, and resources must support the construction, operation, and maintenance of appropriate technical options.

The technologies selected should be the least complex and costly that will provide the desired level of service to consumers while protecting human health and the environment. The simplest, lowest cost option to build, operate, and maintain will generally be the most cost-effective and sustainable choice. When choosing, it is important to consider operation and maintenance requirements and all costs to both users and service providers over the entire life of the facilities.

Improving sanitation in the cold regions is possible, however. The following options are considered most suitable in most cold nonsewered environments:

- **Upgrading and improving existing and new pit latrines** so that they provide a more pleasant user experience while protecting human health and the environment. Pits can be closed, covered, and abandoned when full, or they can be emptied and the contents conveyed to a treatment facility.
- **Container-based sanitation**, in which the feces are directly deposited into a container. When full, the container and contents are conveyed to a facility where the feces are treated for reuse or disposal. Urine can be allowed to soak into the ground, collected separately, or mixed with the feces for treatment. However, this system cannot succeed unless there is an organization that can and will collect and treat the latrine sludge on a regular basis, which requires a high level of logistical capacity.
- **Low-water-use toilets** that flush to soakpits, holding tanks, or septic systems may be an option for households that are willing to support the expense and effort required to construct, operate, and maintain them. Such systems must be designed and built to function in cold temperatures.

It is essential to consider sanitation, including on-site sanitation, as a system, not just a facility. The entire sanitation service chain needs to be considered. Waste must be properly managed from containment to conveyance to treatment and potential reuse or final disposal. Improper use or disposal poses a risk to public health and the environment.

Note

1. Population data are from Population, Total, World Bank Data, Washington, DC (accessed November 19, 2016), https://data.worldbank.org/indicator/SP.POP.TOTL?name_desc=false. Climate data are from Climate Change Knowledge Portal: Historical Data, World Bank Data, Washington, DC (accessed November 19, 2016), data.worldbank.org/data-catalog/cckp_historical_data.

Abbreviations

ACF	Action Contre La Faim (Action Against Hunger)
EcoSan	ecological sanitation
FSM	fecal sludge management
HDPE	high-density polyethylene
JMP	Joint Monitoring Programme for Water Supply and Sanitation
LaDePa	latrine dehydration and pasteurization
lcd	liters per capita (person) per day
NGO	non-governmental organization
SDG	Sustainable Development Goal
UDDT	urine-diverting dry toilet
VIP	ventilated improved pit
WSP	World Bank Water and Sanitation Program

Chapter 1 Introduction

Objective of the Catalog of Technical Options

This Catalog is one part of a study to identify issues and potential technical solutions for improving sanitation in cold regions, where the climate affects the provision of water and wastewater services, with a focus on East and Central Asia. This document focuses on the main question:

> In cold regions, what technological options are most suitable for delivering sustainable improved sanitation in areas that are not served by piped water supply and sewerage networks?

Globally, 2.5 billion people lack access to improved sanitation. Improving sanitation is a challenge around the world. A cold climate adds to that challenge by increasing the complexity of designing, operating, and maintaining sanitation facilities.

What Do We Mean by *Sanitation*?

There is no agreed-on definition of *sanitation*. This report will use the definition from the Sustainable Development Goals (SDGs):

> "Sanitation is the provision of facilities and services for safe management and disposal of human urine and faeces" (UNICEF and WHO n.d.).

The Joint Monitoring Programme for Water Supply and Sanitation (JMP) defines *safely managed sanitation services* as use of an improved sanitation facility that is not shared with other households and where excreta are safely disposed on-site or treated off-site (UNICEF and WHO 2015). An *improved* sanitation facility protects and promotes human health by providing a clean environment and breaking the cycle of disease. It promotes sustainability by being economically viable, socially acceptable, and technically and institutionally appropriate. Box 1.1 gives details.

Box 1.1 Sanitation Is More Than a Toilet

Many people around the world assume that if the "right" sanitation facility for a given context is identified or developed, and made available, then people will adopt and use it. However, experience around the world has demonstrated that far more is involved.

Sanitation facilities must be viewed as part of a service delivery system. They must be affordable and acceptable to potential users, as well as technically feasible. Planners and operators must consider the entire sanitation service chain, and sanitation systems must be supported by appropriate and effective institutional, regulatory, and financial frameworks.

What Do We Mean by *Cold Regions*?

There is no agreed-on definition of what constitutes a cold region, but for the purposes of this Catalog, *cold regions* are defined as regions where the mean monthly temperature is below 1°C for one month or more annually.

There are places where the soil freezes and thaws seasonally on every continent. In the Northern Hemisphere, approximately 58 percent of the land (about 55 million square kilometers) freezes and thaws seasonally. In the Southern Hemisphere, parts of Africa and South America have seasonally frozen ground, and high-altitude areas in South America as well as northern parts of North America, Europe, and Asia have permafrost—that is, ground continuously frozen for two years or more (National Snow and Ice Data Center 2016).

The possible options for feasible, cost-effective systems for cold regions in developing countries are limited. Sanitation facilities and processes can be affected by cold temperatures in the air and the ground even in relatively moderate climates. Many sanitation systems that work well in tropical or temperate regions will not work well, if at all, in freezing conditions. Some systems may require modifications to function effectively in cold temperatures. However, these modifications can be prohibitively costly or complex. For example, pipes or tanks can be prevented from freezing by adding heat using heat tapes or cables, but the cost of electricity to operate them can be unaffordable for users. Box 1.2 discusses Alaska's efforts to find more sustainable solutions for water supply and sanitation.

Box 1.2 The Alaska Water and Sewer Challenge

In 2013, the Alaska Department of Environmental Conservation launched the Alaska Water and Sewer Challenge. Its goal was to significantly reduce the capital and operating costs of water supply and sanitation for rural Alaskan households. In the past, government agencies have subsidized community water supply systems and sewerage networks or advanced truck haul systems. However, the capital and operating costs of these systems have increased sharply while funding has decreased. Consequently, these systems have become unsustainable, even in the relatively wealthy state of Alaska.

Because cold regions vary considerably, options selected for use in a specific place should be evaluated and tested for use in other conditions. The depth of soil freezing and its duration can be difficult to estimate because they are affected by the length and severity of the cold season, the amount of snowfall, hydrogeological conditions, vegetative cover, building density, and more. However, the consequences of soil freezing to a depth of 1 meter are significantly different from those where it freezes to a depth of 4 meters, so local conditions must be considered.

Cold temperatures affect the design, use, construction, operation, and costs of sanitation systems, as well as the processes that take place within them. Some main effects include the following:

- ✓ Key biological, physical, and chemical processes that break down excreta and other organic matter slow and stop.
- ✓ Soil cannot absorb the liquid portion of the waste because frozen saturated soil is impermeable.
- ✓ Pipes, pits, tanks, vaults, and other containers can be blocked or damaged when their contents freeze and expand.
- ✓ Frozen wastewater put into canals or onto land can block drainage canals or create an icy hazard on land and then pollute the surrounding area when it thaws.
- ✓ Soil becomes unstable as the water in the soil pores expands and shrinks as it freezes and thaws, causing movement that can damage and displace pipes, pits, tanks, vaults, and other fixtures.
- ✓ Construction is affected. For instance, digging in frozen soil can be difficult, and concrete will be weak if it freezes while hydrating.
- ✓ Structural design must consider snow and ice loads, as well as drainage for meltwater.
- ✓ Vulnerable populations, including the young and the elderly, may experience increased difficulty using sanitation facilities during cold periods.

How Many People Are Affected?

No matter how cold regions are defined, sanitation options for large numbers of people are limited by cold temperatures. Like this report, the Cold Regions Utilities Monograph (Smith et al. 1996) defines a cold region as one "where the mean monthly temperature of one month per year is below 1°C." In 2015, more than 2.5 billion people lived in countries where the average monthly temperature has historically been below 1°C for at least one month of the year; 1.5 billion lived in countries where it was below -5°C for at least three months of the year.[1] About 4 million live in extremely cold arctic regions (Arctic Council 2015). Table 1.1 summarizes the number of people living in cold countries.

Duration of Cold Temperatures	Population of Areas with Monthly Average Temperatures below:			
	1°C	0°C	-5°C	-10°C
At least one month	2,525,431,312	2,491,560,244	2,015,115,394	260,525,465
At least two months	2,487,335,840	2,297,440,409	1,645,588,175	242,244,739
At least three months	2,250,029,496	2,164,805,935	1,631,745,465	194,063,283
At least four months	1,975,624,794	1,642,901,286	199,545,296	188,106,283
Six months or more	203,717,990	185,477,972	179,951,228	2,642

Table 1.1 Population of Cold Countries

Sources: Population, Total, World Bank Data, Washington, DC (accessed November 19, 2016), https://data.worldbank.org/indicator/SP.POP.TOTL?name_desc=false; Climate Change Knowledge Portal: Historical Data, World Bank Data, Washington, DC (accessed November 19, 2016), data.worldbank.org/data-catalog/cckp_historical_data.

Some people in cold countries may live in warmer parts of the country; conversely, many people in warmer countries live in colder areas, where water and sanitation are affected by the cold—at high elevations, for example. Neither Nepal nor India have any months where the average temperature for the country is below 1°C,[2] though large areas of both countries have very cold winter seasons.

Origin of the Catalog

This Catalog is necessary because surprisingly little attention has been paid to sanitation for cold regions—especially affordable, low-cost sanitation—and little information about potential technical options is readily available. Gaps in knowledge about sanitation in cold regions, described in box 1.3, are considerable. Yet technical problems caused by very low temperatures can add significantly to the cost and complexity of designing, building, operating, and maintaining water and sanitation infrastructure, such as septic systems, sewer networks, or wastewater treatment plants. Moreover, many of the communities and countries affected by very cold climates are remote, poor, and vulnerable. Such communities and nations often find it difficult to pay the capital, operational, and maintenance costs for water and sanitation infrastructure. Common constraints

> **Box 1.3 What Do We Know?**
>
> The gaps in knowledge about sanitation in cold regions are enormous. Interest in sanitation in cold climates is growing, but relatively little is known about sanitization of sludge or of urine in cold temperatures, for example.
>
> Pilot projects have produced fuel briquettes from fecal sludge in temperate regions: would it be possible in cold regions, where there is arguably greater need?

include insufficient and outdated technical capacity, limited political will, and inadequate and outdated regulatory, financial, and institutional frameworks.

Who Is the Catalog for?

The Catalog is mainly intended to provide decision makers and planners with the information needed to identify potential technical options when planning sanitation improvements. It is not meant as a design manual for engineers or technicians, but it does provide references for additional information to ensure that facilities are properly designed, constructed, and operated. The Catalog assumes the reader has a basic understanding of the main low-cost sanitation technologies available; this manual deals only with their application in very cold climates.

Report Structure

This Catalog is divided into sections. The first section is this introduction, presenting the need for more attention to a critical need for many. The second concerns the challenges posed by sanitation globally and in cold regions. The third section summarizes potential solutions for those challenges. The appendix includes definitions of terms used in the Catalog, additional information on sanitation experiences in cold regions, and references.

Photo 1.1 shows a pit latrine—a common sanitation facility in the nonsewered, largely informal, peri-urban part of Ulaanbaatar, Mongolia. More details on the effects of the cold on sanitation are given in Chapters 2 and 3.

Photo 1.1 Pit Latrine Next to Full Pit, Ulaanbaatar, Mongolia
Source: World Bank.

Notes

1. Population data are from Population, Total, World Bank Data, Washington, DC (accessed November 19, 2016), https://data.worldbank.org/indicator/SP.POP.TOTL?name_desc=false. Climate data are from Climate Change Knowledge Portal: Historical Data, World Bank Data, Washington, DC (accessed November 19, 2016), data.worldbank.org/data-catalog/cckp_historical_data.
2. Climate data are from Climate Change Knowledge Portal: Historical Data, World Bank Data, Washington, DC (accessed November 19, 2016), data.worldbank.org/data-catalog/cckp_historical_data.

Chapter 2 : Sanitation Is a System, Not Just a Toilet

The Sanitation Service Chain

Sanitation is more than a toilet facility; it is a system for managing human waste that protects and promotes human health and the environment by keeping untreated excreta out of the environment and away from human contact. A sanitation system is a series of operational elements linked in a sanitation service chain. Each link must be economically viable, socially acceptable, and technically and institutionally appropriate. Links in a typical sanitation service chain are illustrated in figure 2.1.

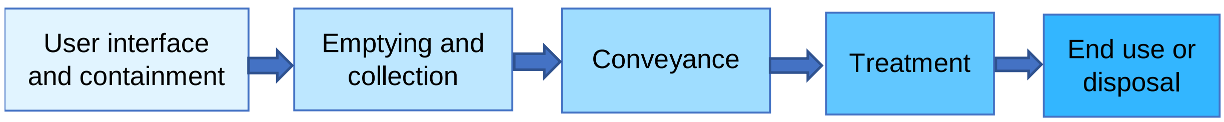

Figure 2.1.1: Typical Sanitation Service Chain

The chain, or system, consists of a combination of some or all the following links, or elements:

- **User interface and containment:** The toilet fixture captures the excreta and is the first element in the sanitation system. The slab or platform that supports the user and the toilet fixture, and the superstructure that provides privacy and shelter, are also important to the user experience.

  For on-site systems, some type of pit, vault, tank, movable container, or other receptacle receives and contains the waste.
- **Emptying and collection:** Many systems, especially on-site and hybrid sanitation systems, require a mechanism for removing waste from containment and collecting it.
- **Conveyance:** The collected waste must be transported away from the toilet facility, unless the waste is stored on-site indefinitely. For on-site systems, conveyance is generally by vehicle.
- **Treatment:** The waste must often be treated so that it can be reused or disposed of without risk to public health or the environment.
- **End use or disposal:** After adequate treatment, waste can safely be reused or disposed of.

Not all systems require all the elements. More details are given in Chapter 3.

Types of Sanitation Systems

Dry and Water-Flushed (Wet) Toilet Options

The basic toilet choice is between a dry toilet, which requires no water for use, and a wet water-flushed toilet. In both cases, many variations are possible. Urine can be mixed with fecal matter, or it can be diverted in specially designed toilets, such as urine-diverting dry toilets (UDDTs), and treated separately. Although urine diversion can be used for both wet and dry systems, it is more common in dry systems.

Wet systems will function only when all elements of the system are protected from freezing. They require sufficient water to flush excreta away from the toilet and carry it through pipes to treatment plants, septic tanks, holding tanks, or other facility for containment, treatment, or disposal. The necessary volume of water will normally be available only when there is a reliable connection to a water supply system or a high-yielding well near or at the toilet facility.

Dry toilets are the only feasible option when water availability is less than about 25 liters per capita (person) per day (lcd), though they can be used even when larger volumes of water are available. However, separate arrangements may be needed to dispose of greywater—that is, wastewater from domestic uses, such as laundry or cooking, that does not contain excreta. Greywater disposal is a challenge in cold climates, where it cannot soak into frozen ground. Some dry latrines can handle small amounts of greywater without much oil, grease, or fats, which can plug soil pores and prevent infiltration. Many wet sanitation options can handle both greywater and water from toilets (blackwater). If dry toilets are used, but water consumption is high, separate provision for greywater will be needed. Figure 2.2 summarizes how water availability can influence sanitation choices.

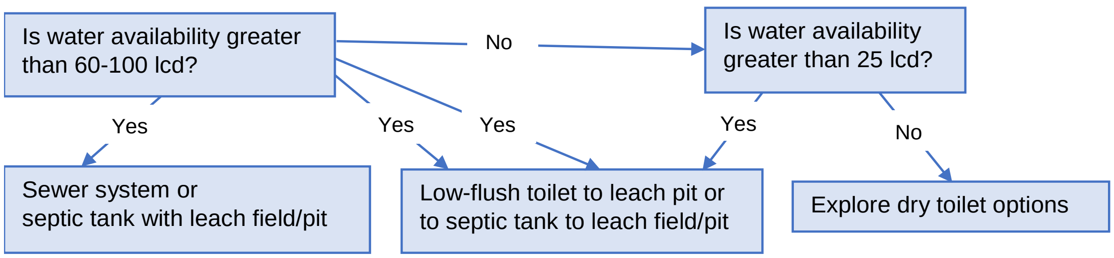

Figure 2.2 Effect of Water Availability on Sanitation Choice

On-Site, Off-Site, and Hybrid Options

Both wet and dry toilets can be on-site or off-site sanitation, or a combination of the two, often called hybrid sanitation. An on-site system can be defined as one in which excreta are partially or fully treated on-site, in or near the toilet facility. In an off-site system, excreta are removed soon after defecation for further treatment. In a hybrid system, some excreta are treated on-site, either fully or partially, and the rest are conveyed off-site for treatment and disposal.

Common dry sanitation options include the following:

- **Pit latrines**, where excreta drop into a pit below the toilet. Solids are retained and decompose in the pit while liquids infiltrate into the soil surrounding the latrine.
- **EcoSan (ecological sanitation) latrines**, which are intended to treat excreta for reuse, usually as a nutrient-rich soil additive. In cold regions, additional treatment off-site will be needed to ensure safe reuse or disposal.

Wet sanitation can be off-site or on-site systems. Common options include the following:

- **Low-flush or pour flush toilets**, connected to a leach pit that retains the solid waste, which is periodically removed for further treatment, while liquid effluent infiltrates into the ground
- **Vault latrines**, which hold excreta in a watertight vault for frequent emptying and collection
- **Flush toilets with offset septic tanks**, where solids settle out and are periodically removed for additional treatment, while liquids infiltrate into the soil in a leach pit or leach field

In wet off-site systems, excreta are removed from the toilet site for further treatment. Some common options for off-site systems include the following:

- **Sewerage**, where wastewater is conveyed off-site via sewer pipes for treatment or disposal
- **Flush-tank-haul systems**, in which wastewater is kept on-site for a short time in a holding tank or other container, which is emptied regularly and the contents taken for treatment

An example of a hybrid wet system is as follows:

- **Settled sewage**, also called solids-free sewage, in which the solids are retained in an interceptor tank for some time and removed periodically for further treatment. The liquid flows into a sewer system, which conveys it to a treatment facility, where it is treated for reuse or safe disposal.

A dry hybrid system is as follows:

- **Container-based sanitation**, which involves the on-site collection of feces in a movable container. Full containers are periodically collected and conveyed to a facility where the contents undergo further treatment for reuse or safe disposal.

How Links/Elements in the System Affect Each Other

Because elements in a sanitation system are linked, choices and decisions relating to one element influence choices and decisions regarding other elements. Whether sanitation is wet or dry influences emptying and collection, conveyance, and treatment; for instance, sewers can be used only with wet sanitation. Sewage can be treated in wastewater treatment plants, whereas the more concentrated fecal sludge from a pit latrine or septic tank can shock and disrupt treatment processes at plants that have been designed to treat sewage.

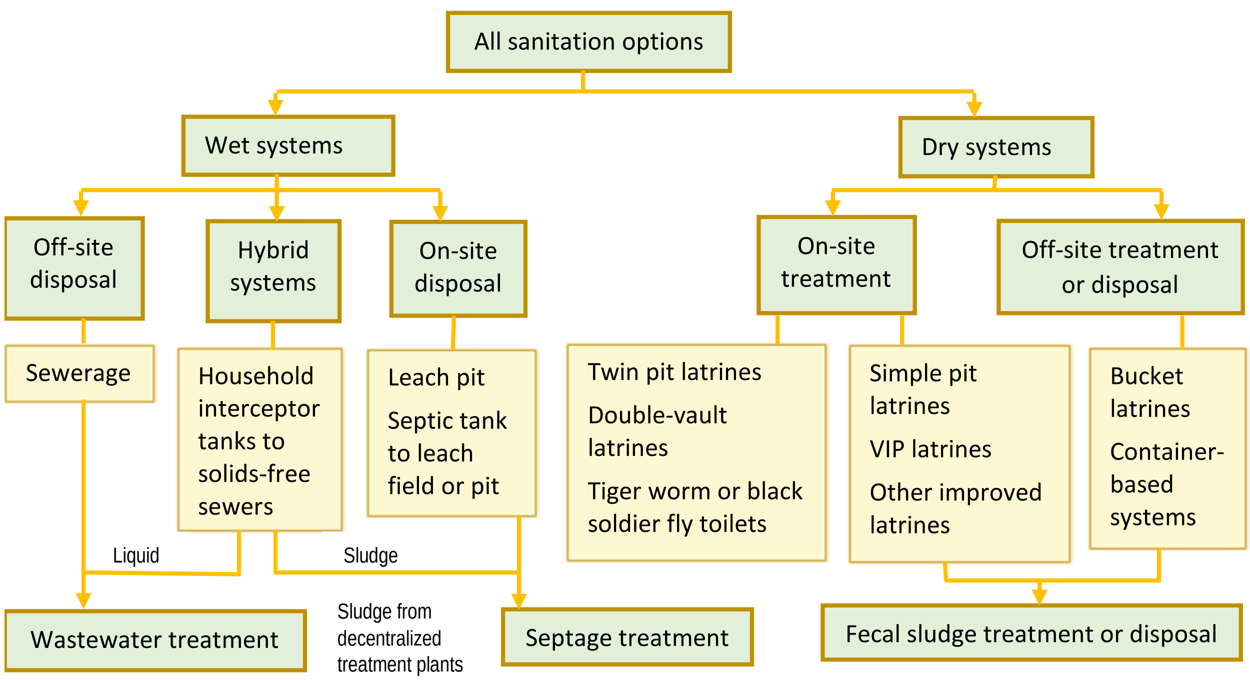

Figure 2.3: Common Sanitation Options
Source: Kevin Tayler, personal communication, April 24, 2017.

Treatment and disposal requirements vary for on-site or off-site options as well. Off-site treatment requirements differ with the degree of on-site treatment (Strande, Ronteltap, and Brdjanovic 2014). Urine handling will also affect options; urine that soaks into the ground will not need treatment. Figure 2.3 presents ways that toilet choices can influence choices for the storage, transport, and treatment of excreta and wastewater.

Level of Service

The level of service provided by a sanitation system refers to the quality of service provided by the system. It depends on the type and quality of the sanitation facilities, their location, and the adequacy of the management arrangements. As noted in box 2.1, the simplest option that offers the desired level of service will often be the most cost-effective and sustainable option.

> **Box 2.1 Choice of technology**
>
> Many people around the world think that "high-tech" solutions will always offer a higher level of service than older, "simpler" technology. However, readily available, proven solutions that do not require special skills, materials, parts, or equipment—and that do not cost large amounts of users' time, money, or effort—are often the most suitable and cost-effective option. For example, septic systems consisting of a septic tank and leach field are simple and inexpensive to operate, yet they offer a high level of service. In rural areas of the United States, they have been commonly used since the 1940s and are still frequently chosen for new housing.

When consumers choose a sanitation system, their perception of the level of service offered is important. Planners must consider local ideas about acceptable toilet use, location, and design, which vary from culture to culture and place to place. Some people may consider an indoor toilet to be disgusting; others may consider it the most desirable option.

The basic options for location, in order of increasing levels of service, include the following:

- **Communal or public toilets** located away from individual plots
- **Shared toilets**, perhaps located on shared household plots and accessible to several households
- **Household toilets located outdoors**, normally on individual plots
- **Household toilets located indoors**, inside the dwelling

A household toilet can be located inside the house or outside, near the house. A clean and well-maintained indoor toilet can offer optimal convenience, security, and comfort, especially in cold regions. It is more likely than an outdoor toilet to be located near a basin or tap, with soap for handwashing after defecation, so it may offer greater health benefits. Most indoor toilets have water seals that control smells and the movement of insects and rodents, so they are well-suited for indoor use. Separating urine and feces also reduces odors, so UDDTs can, in principle, be located inside houses. In fact, UDDTs are used inside homes in Sweden, Alaska, and Greenland, among others. However, it can be challenging to convince people that dry toilets can be free of odors and other nuisances and to ensure that users manage the toilets correctly so that they function properly.

Sanitation systems of any type that are not well-designed, well-constructed, well-managed, or well-maintained will normally offer a low level of service and will not protect human health and the environment. A poorly maintained sewer or wastewater treatment plant can pollute groundwater and pose a risk to human health and the environment. Indiscriminate dumping of sludge from a wastewater treatment plant can also pose a risk and a nuisance. At the same time, a well-built simple pit latrine that is kept clean and managed well can safeguard human health and the environment and will be more pleasant to use than a dirty flush toilet.

Improved services include safe management of fecal sludge—that is, excreta removed from on-site sanitation facilities. Fecal sludge management (FSM) covers containment, emptying, collection, conveyance, treatment, and safe disposal or reuse of fecal sludge. FSM also includes the operation, maintenance, and repair of the system, as well as resolution of any failures caused by either technical or managerial issues.

Authorities have an important role in FSM for all sanitation service chains. The government must develop the standards, policies, and regulations for sanitation systems—and then disseminate and enforce them. Local authorities should also develop and support institutions that can assist homeowners, designers, and builders to ensure that pit latrines are correctly sited, designed, and built to protect human health and the environment. Government agencies may also have a role to play in enhancing the supply chain to help ensure that products to improve pit latrines are available on the market.

Effects of Cold Temperatures on the Sanitation Service Chain

As described earlier, cold temperatures affect the processes on which all sanitation systems depend, as well as their construction. The effects of the cold will depend on the duration and intensity, which vary from place to place. The use of modern, high-quality construction techniques, materials, and components that resist freezing is especially important.

User Interface and Containment

Toilet/User Interface (Capture)

The effects of cold temperatures on the user interface depends heavily on whether the facility uses wet or dry sanitation. In cold regions, toilets with a water seal or a cistern for water for flushing can be in a heated place only, such as a house. When exposed to freezing temperatures, the water will freeze, blocking the toilet, and expand, damaging fixtures and pipes. If pipes, fixtures, tanks, and fittings are not located in a heated enclosure, they must be insulated and equipped with heat tape or other means to keep them from freezing and to thaw them in case of accidental freezing.

Dry sanitation is generally well-suited to cold regions, though excreta can freeze in the pits, as shown in figure 2.4. If UDDTs are used, they must be carefully designed so that the urine does not freeze in and block fixtures or pipes.

If users want a toilet with a seat, materials must be chosen carefully. Very cold temperatures freeze human skin rapidly (even from a cold seat), so appropriate, well-insulating materials are needed. Seats can be heated but only where there is a reliable source of electrical power and people are willing to pay for it.

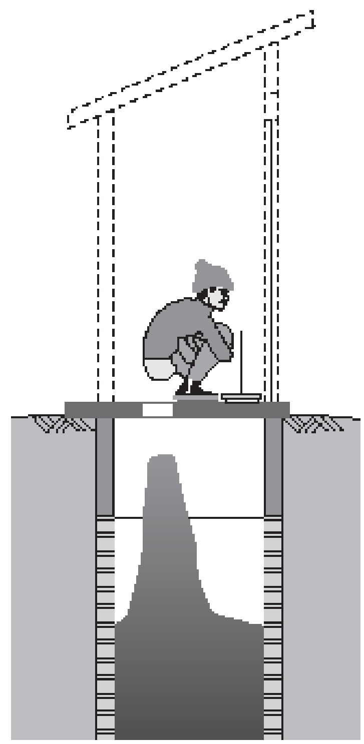

Figure 2.4 Pit Latrine with Frozen Excreta

Source: Adapted from WEDC, Loughborough University.

Superstructure/Shelter

Where the superstructure is outside of the house, it should shelter users from the cold as much as possible. In some cases, snow loads on the structure or sloped roofs to shed snow may need to be considered.

For wet sanitation options, the superstructure must be heated so that the liquid in the toilet, pipes, and other fixtures will not freeze, which would block and possibly damage them. Therefore, placing wet sanitation facilities inside a heated home may be more cost-effective than placing them in a separate structure that must also be heated. In-house facilities frequently consist of a room(s) with a reliable water supply, flush toilet, sink, and bathtub/shower and possibly a sink in the kitchen and a washing machine or laundry sink in the house as well. Liquid must be drained from pipes and fixtures if the temperature in the house is expected to drop below freezing.

Containment (Container, Pit, Tank, or Vault)

The cold can and does freeze wastewater in pits and vaults if they are not (a) in or below a heated building; (b) protected by insulation and/or mechanisms to add heat, such as heat tape; or (c) extended below the depth at which the soil freezes. Moreover, during the cold season, the air in pits, tanks, or vaults can conduct cold from the surface to the soil around the pit, causing that soil to freeze to a greater depth than the soil farther from the pit, tank, or vault.[1]

Both liquid and solid waste will accumulate in pits, tanks, vaults, or other containers during the cold season because it cannot be emptied when frozen and liquid cannot infiltrate into frozen soil. Pits, tanks, vaults, and other containers must, therefore, be sized to hold all the wastewater generated during the cold season. Also, the reduction of volume of the fecal matter that occurs during decomposition will slow and stop during the cold season, so accumulation rates will be greater in cold climates.

In the active zone where soil freezes and thaws, pit linings, tanks, and vaults must be carefully designed and constructed to avoid damage from soil movement. This movement, in addition to freezing and thawing excreta inside, can exert tremendous pressure and crack or displace the walls. This damage can cause watertight tanks or vaults to leak. Freestanding containers must also be resistant to the cold.

When the warm season starts, drainage from melting ice and snow must be controlled so that the meltwater does not enter the pit.

Frozen waste can form a solid pyramid below the place where the waste enters the pit, eventually blocking the waste entry point where the user defecates. In Mongolia, users reported manually knocking down the heaped excreta. They also defecated at different points along the length of the opening between the floor planks, over time distributing the excreta in an elongated pile, which did not rise as high as a heap below a smaller defecation hole.

Emptying and Collection

In general, pits, vaults, and tanks cannot be emptied if their contents are frozen. Therefore, it may be necessary to empty the pit, vault, or tank at the start of the cold season to ensure that there is enough empty space to store all the waste generated during the winter. Although it may be possible to manually break up frozen waste and remove it from unlined pits, this option is not recommended because of potential environmental and health risks. In fact, good practice is required for all emptying, collection, and conveyance methods to protect workers and to prevent the spread of excreta into the environment.

Conveyance

Conveyance will be affected by the cold, whether by vehicle or through sewer pipes.

Vehicles, equipment, and containers used to transport fecal sludge, such as that emptied from latrine pits or septic tanks, should be resistant to freezing and cold temperatures. With container-based systems, open trucks or trailers may be used; the use of appropriate containers can reduce or eliminate damage from freezing. For liquid waste that is not frozen, tankers, like the one shown in photo 2.1, can be equipped with insulated tanks. Vehicles may need to be equipped with special tires or chains for traction on icy roads. Also, water for washing vehicles can present an icy hazard if it spreads over the ground.

Sewer pipes, and their contents, can freeze, blocking and damaging pipes and joints. To prevent freezing, pipes can be buried below the frost line or routed through a utilidor, an insulated or heated conduit. Lines passing through the active zone where the soil freezes and thaws, or lines exposed to freezing air, should be well-insulated and may need to be equipped with heat tape to prevent freezing and to thaw them in case of accidental freezing. Flexible joints can help prevent damage from soil movement. Also, vents on pipes must be kept clear of ice and snow because the toilet trap can siphon dry if a vent freezes shut. The liquid in the traps prevents the system from venting indoors, so dry traps can permit odors to enter the building (Cold Climate Research Center n.d.).

Photo 2.1 Vacuum truck, Ulaanbaatar, Mongolia
Source: © GV Jones & Associates, Inc. Used with the permission of GV Jones & Associates, Inc.

Treatment

Biological processes are heavily temperature-dependent, and they slow and stop in cold temperatures: "Biological activity often doubles for every 10°C increase in temperature within a given growth range for each microorganism. Each microorganism has a minimum temperature, that is, the point below it cannot grow; an optimum temperature range, where enzymatic reactions happen at their greatest possible rate; and a maximum temperature, above which microorganisms can no longer grow due to denaturation of proteins" (Strande, Ronteltap, and Brdjanovic 2014, 56). Some pathogens, including bacteria, can survive freezing but not others. Many helminth eggs and viruses can survive freezing temperatures for long periods under many conditions. Overall, the effect of very low temperatures on decomposition and on the survival rate of pathogens in excreta is complex and not fully understood.

Because biologic activity reduces in cold temperatures, physical and chemical methods may be required to stabilize and sanitize the excreta. However, many chemical and physical processes are also affected by cold temperatures, so they can be used for treatment only in the warm season. Neither lime nor urea can react with ice, so they are unable to treat frozen sludge, for example.[2] During treatment of fecal sludge with urea, rates of pathogen reduction and inactivation decrease as the temperature also decreases (Nordin, Ottoson, and Vinnerås 2009). Physical processes can also be affected because the viscosity of liquids increases as temperature decreases, affecting, among other factors, filtration or rates of particle settlement (Ridenour 1930).

Many sanitation systems depend on infiltration into the soil to treat the liquid portion of the waste. However, liquid cannot soak into frozen soil, so leach pits and leach fields that freeze will not function.

End Use/Disposal

As mentioned earlier, appropriately treated excreta have many uses. However, end use can be affected by cold temperatures. In cold regions where agriculture is limited, there may be little demand for fertilizer or soil conditioner made from treated excreta. If there is a demand, it will be limited to the warm season. Biogas plants that produce gas from excreta do not function well in cold temperatures either because the amount of gas produced drops precipitously with the temperature (Balasubramaniyam et al. 2008). They cannot be recommended where the temperature in the plant will drop below 5°C.

In cold regions where fuel is scarce or costly, researchers could investigate the conversion of excreta into fuel pellets that households could burn for heat.

Selection Factors

There is a tendency to think that people will improve their sanitation once they have access to the "correct" technology and have been informed of its advantages. Experience around the world has shown, however, that many other factors affect people's willingness to invest in sanitation.

To be able to choose appropriate, sustainable, sanitation technologies, consumers must have access to, and knowledge of, options for improving sanitation. For each potential option, they need information on the implications and requirements for construction, use, maintenance, costs, expected life, energy use, and more. For example, some households surveyed in Mongolia wanted flush toilets outside the house (Roger 2015). They apparently did not realize the cost and difficulty of preventing the water in the fixtures and pipes from freezing.

Available Services

The feasibility of sanitation options depends in part on the municipal services available to the household. For example, people cannot connect to a sewer if there are no sewer mains nearby. Households cannot use wet sanitation of any type unless the necessary volumes of water are available, which normally requires access to a piped water system. Thus, for many people without access to municipal sewer services, dry on-site sanitation options will be the most appropriate choice.

Geohydrologic Conditions

Geohydrologic and climatic considerations including, among others, precipitation, ground slope, depth to bedrock, depth of the water table, and type of soil will affect the type, design, costs, construction, operation, and maintenance of sanitation facilities. For example, it is difficult to dig latrine pits or trenches for water supply and sewer networks if the bedrock or the groundwater is close to the surface. This is especially true if pipes must be buried below the depth of soil freezing.

Demographic Conditions

Population density affects the choice of sanitation. Higher population densities may favor sewer networks because per capita construction and maintenance costs—as well as the environmental impact—for water supply and sewer networks decrease sharply as population density increases (Mara 1996; Roux et al. 2011). Low-density housing can favor on-site options because there is adequate space for them and their eventual replacement.

Photo 2.2 Peri-Urban Area of Ulaanbaatar, Mongolia
Source: World Bank.

Some options require more space than they would in warmer places and are, therefore, more difficult in densely populated areas. Pits, tanks, or vaults for on-site options may need to be larger to contain all the waste generated during the cold season and accommodate the slower rates of biological breakdown and reduction in volume. Deep excavations to bury facilities below the depth of soil freezing must be either shored or large enough to prevent collapse. Considerable space will be needed to store excavated soil during construction.

Land tenure and housing conditions generally have a strong effect on public services, including water and sanitation. Owners who live on their own property are typically more likely than tenants or squatters to be willing to pay for sanitation and other improvements to their residences.

Photo 2.2 shows a nonsewered peri-urban area of Ulaanbaatar, Mongolia.

User Preferences and Affordability

People's usual customs and preferences will—or should—influence sanitation options. For instance, in countries with strong taboos around excreta, it may be difficult to convince people to use technologies that require any contact with feces, such as EcoSan latrines.

Households also vary in their willingness and ability to invest in improving their sanitation facilities. People may be willing to invest in costlier options that offer a higher level of service. Because households' economic means and preferences can vary greatly, even within the same area, initiatives to improve sanitation should offer a range of options that suit potential consumers' preferences and economic situations. These initiatives should identify people's motivations for improving sanitation and tailor promotional activities to those motivations.

Construction, Operation, and Maintenance Requirements

Although people often assume that high-tech solutions are superior to low-tech options, in practice, the less complex and costly a system is to build, operate, and maintain, the more likely it is to be used and operated correctly in the long term. Moreover, for a sanitation option to be feasible, the materials and skills to plan, design, and build or install, operate, and maintain it must be locally available. Thus, the costs and complexity of constructing, operating, and maintaining systems throughout its lifetime, at all levels, should be considered when selecting a sanitation technology.

Household Level

Households are generally entirely responsible for building, operating, and maintaining the on-site elements of sanitation systems. Depending on the system, users may need to alter their behavior to correctly use and maintain their improved sanitation facilities. For example, the use of UDDTs may require some adaptation. In other cases, users may need to pay to empty pits, tanks, vaults, or containers and coordinate with emptiers who collect the waste. For wet sanitation systems, users also need to ensure a reliable supply of water and that pipes, tanks, and fixtures do not leak or freeze.

Institutional Level

Unless household latrine pits are closed, covered, and abandoned when full, the government or its designee is—or should be—responsible for managing fecal sludge from latrines, septic tanks, and other on-site facilities. Local authorities, or an organization supervised by the authorities, are, therefore, responsible for building or purchasing, operating, maintaining, and managing equipment and facilities for containment, emptying and collection, conveyance, treatment, and end use or disposal as needed. Even where the private sector performs some functions, the government must regulate and oversee their work.

Appropriate standards, policies, and regulations for FSM must be established, disseminated, and enforced. Local authorities can also develop and support institutions that can assist homeowners, designers, and builders to ensure that sanitation facilities are correctly sited, designed, and built to protect human health and the environment. Government agencies may also have a role to play in enhancing the supply chain, ensuring that products to improve sanitation are available on the market.

Local authorities can promote sanitation improvements—for example, by building demonstration latrines that show that latrines can be clean, comfortable, and attractive, without flies or odors, at a low or moderate cost. Authorities at the national level and external partners can also work on developing alternate technologies that, for instance, use solar power to dry excreta or reuse sludge to make fuel pellets that householders can use to heat homes.

Authorities can also promote handwashing at critical moments, including after defecation, and other hygiene behaviors that break the cycle of disease transmission and maximize the health benefits from improved sanitation. Handwashing promotion campaigns are common in developed countries because handwashing can prevent the spread of colds and influenza as well as diseases related to sanitation.

Expected Costs

The life cycle costs of sanitation improvements include two separate but equally important types of costs: capital costs and operation and maintenance costs.

Capital Costs

In general, for a given level of service, capital costs, composed of the costs of construction and installation—including land, materials, transportation, and labor—will be higher in cold regions than in warmer ones. Larger pits, tanks, or vaults to contain frozen excreta or expensive measures to prevent freezing, such as insulation or burying the installations deeply, may be necessary. Although more costly initially, good construction practices and appropriate, modern, high-quality materials are likely to lower operational and maintenance and repair costs, saving money over the life of the facilities. These measures can include the use of adequate insulation, high-density polyethylene (HDPE) pipe, or insulated arctic pipe that resists freezing, as well as flexible couplings that can resist soil movement, among others.

Operation and Maintenance Costs

Costs will vary according to the sanitation option chosen, but operation and maintenance costs should be expected to be higher in colder climates than in warmer climates for similar sanitation systems. For example, wet sanitation options may need to add heat to the system to prevent freezing during the cold season by housing facilities in a heated enclosure or by operating heat tapes.

Expected Life

One of the factors affecting the selection of a suitable sanitation facility is its design life—that is, how long the facility is expected to last before it must be replaced or undergo major rehabilitation. The life of a well-built and properly used and maintained on-site sanitation facility depends largely on the life of the pit, tank, or vault. In situations where the pit fills and cannot be emptied, the latrine must be replaced every time the pit, tank, or vault is full. If the latrine or vault can be emptied periodically, then it can last for years or decades. It may be cost-effective to spend more money on a facility that will last longer, when possible. Not replacing the facility will save space as well as money.

The Enabling Environment

Global experience has shown that an enabling environment is critical to sustaining and replicating large-scale sanitation improvements and may be even more important in cold regions where options are limited, costly, and complex. According to the World Bank's Water and Sanitation Program, the enabling environment encompasses eight components (WSP n.d.):

- Policy, strategy, and direction
- Institutional arrangements
- Program methodology
- Implementation capacity
- Availability of products and tools
- Financing
- Cost-effective implementation
- Monitoring and evaluation

An enabling environment "allows for innovation through supportive policy, institutions, capable public and private actors and effective participation. Stakeholder participation, institutional development and capability development are key elements of an enabling environment that need particular attention" (Lüthi et al. 2011).

Institutional Framework

Appropriate institutional arrangements are essential for the successful operation of improved sanitation systems. At the national level, the responsible agency would define national policies and strategies, plan investments, set regulations, and enforce policy (Livingstone, Erdenechimeg, and Oyunsuvd 2009). In short, it would create an enabling environment where sector stakeholders can work together to improve sanitation. At the subnational level, government institutions would be responsible for planning, supervising and monitoring sanitation interventions, and enforcing regulations.

Regulatory Framework

Inadequate sanitation can pose a serious risk to public health and the environment, so an appropriate regulatory context must be established and enforced. Regulations for sanitation should set minimum standards for acceptable facilities and their location for various levels of service; define performance standards for service providers; and address water pollution and water quality issues (Livingstone, Erdenechimeg, and Oyunsuvd 2009). They should be achievable and allow for innovation and consumer choice, and they should be allowed to evolve as the sector evolves. Regulations should cover the entire sanitation service chain, including FSM, and must be disseminated and enforced.

Financial Arrangements

According to the World Bank, to meet the Sustainable Development Goals (SDGs), the water sector globally will require new strategies based on Sustainable Cost Recovery principles, which recognize that subsidies may be needed to support improved water and sanitation services, at least for a transition period. Financial planning must be part of broader sector planning that addresses policy priorities, the roles and responsibilities of government agencies, and related legislative and regulatory reforms to ensure that the proposed plans are financially viable. Transparency and stakeholder participation in planning, budgeting, expenditure management, implementation, and service delivery are also essential.

Notes

1. Jim Crum, personal correspondence, February 2015.

2. Björn Vinnerås, personal communication, May 11, 2017.

Chapter 3 : Technical Options for Improving Sanitation

The technologies selected should be the least complex and costly that provide the desired level of services to consumers while protecting human health and the environment; this will generally be the most cost-effective and sustainable option. Costs to users and to providers over the entire life of the facilities must be considered.

Summary of Technological Options

The following tables present the suitability of different nonsewer sanitation options for improving sanitation in cold regions: Table 3.1 lists the options for dry sanitation. Table 3.2 covers wet sanitation options. More details can be found in subsequent sections of Chapter 3. Photo 3.1 shows a typical pit latrine in Ulaanbaatar, Mongolia.

Photo 3.1 Typical Pit Latrine in Ulaanbaatar, Mongolia
Source: World Bank.

Notes on Use of Tables

Sanitation options fall into several generic types with many variations. The first row of any generic type gives information that is common to all variations. Subsequent columns provide information on variations only where they differ from the generic description.

The tables give only comparative costs between different technologies because actual costs of technologies vary widely with the location as well as the model chosen. For an effective sanitation chain, costs must be borne by individual users/households and by the institutions that manage and regulate the communal elements of the technology. They are, therefore, shown separately.

Dry Options

Dry sanitation facilities require little or no water to use, and generally cost less to install than “wet” options. Fecal matter can be treated and stored on-site or can be removed for safe disposal or treatment off-site.

Sanitation Type	Variations	Advantages of Use in Cold Regions	Disadvantages of Use in Cold Regions	Operational Requirements	Cost
Improved simple pit latrine ***Recommended low-cost option***		Improvement of low-cost systems already widely used in cold regions. Can be improved incrementally. Pit can absorb small quantities of greywater.	Odor and fly breeding issues if poorly constructed or maintained. Must be located outside house. Accumulation of excreta in the cold season can become objectionable to users. Possible groundwater contamination where large numbers of latrines are present.	**User level:** Regular cleaning of the user interface. Occasional sludge removal or construction of new latrine when pit is full. **Institutional level:** Ensure operation and maintenance of communal elements of sanitation services.	**User level:** Construction: Low Operation: Zero if no emptying or low for emptying. **Institutional level:** Construction: Zero if no emptying or medium to high for fecal sludge collection and conveyance vehicles and treatment facilities. Operation: Zero if no emptying or high for sludge collection, conveyance, and treatment.

Sanitation Type	Variations	Advantages of Use in Cold Regions	Disadvantages of Use in Cold Regions	Operational Requirements	Cost
	Raised pit latrine ***May be suited for use in difficult areas***	Appropriate for rocky areas or areas with the water table near the ground surface.	Users with limited mobility may face access difficulties.	**User level:** Same as pit latrine with periodic emptying. Users may need to protect it from erosion. **Institutional level:** Same as pit latrine with periodic emptying.	**User level:** Construction: Somewhat higher than simple pit latrine. Operation: Same as simple pit latrine with emptying. **Institutional level:** Construction: Medium to high for fecal sludge collection and conveyance vehicles and treatment facilities. Operation: High for sludge collection, conveyance, and treatment.
	Arborloo ***Recommended if households have space for multiple pit latrines and want trees***	Rapid construction and minimal costs.	Minimal user comfort and protection. Increased problems with frozen solids intruding on user interface. Requires space for trees.	**User level:** Periodic digging of new pit and transfer of superstructure. Tree planting and care. **Institutional level:** Minimal requirements.	**User level:** Construction: Very low. Operation: Very low. **Institutional level:** Construction: Zero. Operation: Zero

Sanitation Type	Variations	Advantages of Use in Cold Regions	Disadvantages of Use in Cold Regions	Operational Requirements	Cost
	VIP latrine ***Not recommended***	Controls odor and flies if properly designed, constructed, and used.	Proper construction and use are rare because principles and details of design and operation are often misunderstood by users or builders. Requires a dark superstructure, which is unattractive to many users, especially children.	**User level:** Like simple pit latrine, but fly screen on vent pipe must be regularly cleaned and periodically replaced. **Institutional level:** Operation and maintenance of communal elements of the sanitation service chain.	**User level:** Construction: Slightly higher than simple pit latrine. Operation: Like simple pit latrine. **Institutional level:** Construction: Medium to high for fecal sludge collection and conveyance vehicles and treatment facilities. Operation: Zero if no emptying or high for sludge collection, conveyance, and treatment.
	Double pit toilets ***Not recommended***	Incremental construction of smaller pits (one pit at a time) can reduce startup cost.	Requires additional treatment for safe reuse, negating advantage of on-site treatment, because of uncertainty about length of time required to reduce pathogens to safe levels in cold temperatures.	**User level:** Pits are used and emptied alternately. **Institutional level:** Operation and maintenance of communal elements of sanitation services (collection, conveyance, and treatment).	**User level:** Construction: Higher than simple pit latrine but can be incremental. Operation: Requires periodic emptying. **Institutional level:** Construction: Medium to high for fecal sludge collection, conveyance, and treatment facilities. Operation: High for sludge collection, conveyance, and treatment.

Sanitation Type	Variations	Advantages of Use in Cold Regions	Disadvantages of Use in Cold Regions	Operational Requirements	Cost
Container-based system (with or without urine diversion) ***Recommended if, and only if, there is an organization with the necessary logistical capacity and facilities and if people want the products***		No contamination of groundwater. Nutrients are recycled. Suitable for use in rocky areas and those with high water table.	Off-site treatment is required to reduce pathogens to safe levels. Urine diversion pipes can freeze and block. Usually located outside the house. Collection and conveyance may be difficult in the cold season.	**User level:** Requires good coordination with collection agency for regular emptying. **Institutional level:** Operation and maintenance of communal elements of sanitation services (collection, conveyance, and treatment).	**User level:** Construction: Medium Operation: Medium to high for regular collection. **Institutional level:** Construction: Medium to high for fecal sludge collection and conveyance vehicles and treatment facilities. Operation: High for sludge collection, conveyance, and treatment.
	In-house bucket toilet with off-site treatment ***Not recommended***	Toilet can be inside the house. Can be used to supplement other sanitation systems. Easy access for people with limited mobility.	User must handle fresh excreta, with risk of spillage, or use plastic bags, which complicates treatment. Odor and nuisance issues may be unacceptable to users and visitors.	**User level:** Frequent emptying; may need to clean the bucket after emptying. **Institutional level:** Same as container-based system.	**User level:** Construction: Very low. Operation: Medium to high for collection. **Institutional level:** Same as container-based system.

Sanitation Type	Variations	Advantages of Use in Cold Regions	Disadvantages of Use in Cold Regions	Operational Requirements	Cost
	Double-vault EcoSan toilet with on-site treatment, with or without urine diversion ***Not recommended***	There are few, if any, advantages over container-based system.	Additional treatment off-site is needed before disposal or reuse, which negates advantages. Requires user to handle untreated or partially treated excreta.	**User level:** Vaults must be emptied periodically. **Institutional level:** Operation and maintenance of communal elements of sanitation services (collection, conveyance, and treatment).	**User level:** Construction: Medium. Operation: For emptying. **Institutional level:** Construction: Medium to high for fecal sludge collection and conveyance vehicles and treatment facilities. Operation: High for sludge collection, conveyance, and treatment.
	In-house composting unit ***Not recommended***	For indoor use; complete unit should offer a high level of service with reduced odors or other nuisances. Products are safe for reuse. Many models are manufactured but may not be available locally.	Requires user training and high level of attention and engagement. Poor operation can cause odors. Most models require reliable 24-hour electrical power. The unit, and spare parts, must be imported.	**User level:** Must have access to expertise and spare parts to install, maintain, and repair toilet. May require the addition of organic materials such as sawdust or moss. **Institutional level:** Monitor safe use.	**User level:** Construction: High. Operation: Medium to high for electric power and expert maintenance, and possibly for organic material. **Institutional level:** Construction: Zero. Operation: Zero.

Table 3.1 Summary of Dry Sanitation Options

Note: EcoSan = ecological sanitation; VIP = ventilated improved pit.

Wet Sanitation Options

All water-flushed options have the advantage that the toilet can be located inside the house, increasing user convenience and satisfaction and creating conditions for improved hygiene. In fact, in cold regions, they must be located inside the house or another heated enclosure. The summary information in table 3.2 relates to the options for storage, transport, and treatment of the waste from water-flushed toilets.

Sanitation Type	Variations	Advantages of Use in Cold Regions	Disadvantages of Use in Cold Regions	Operational Requirements	Cost
Low-flush toilet to on-site soakpit ***Recommended for users with access to at least 15 to 25 lcd of water***		High level of service. Controls odors and insects and easy to keep clean. Location inside house is convenient and easy to use, especially for children and for people with limited mobility. Soakpit may be able to handle small amounts of greywater.	Toilet fixture and connecting pipework must be protected from freezing. Pit may fill in cold season. Greater risk of groundwater contamination than simple pit latrine because of greater amounts of liquid.	**User level:** Periodic sludge removal. Prevention of freezing. **Institutional level:** Operation and maintenance of communal elements of services (collection, conveyance, and treatment).	**User level:** Construction: Low to medium. Operation: Medium for emptying. **Institutional level:** Construction: Medium to high for fecal sludge collection and conveyance vehicles and treatment facilities. Operation: High for sludge collection, conveyance, and treatment.

Sanitation Type	Variations	Advantages of Use in Cold Regions	Disadvantages of Use in Cold Regions	Operational Requirements	Cost
	Low-flush toilet with watertight holding tank ***Not recommended***	No contamination of groundwater. Accepts greywater. Suitable for users with higher water consumption.	Toilet fixture, tank, and connecting pipework must be protected from freezing.	**User level:** Frequent emptying of holding tank is required. Prevention of freezing. **Institutional level:** Operation and maintenance of communal elements of sanitation services (collection, conveyance, and treatment).	**User level:** Construction: Medium to high. Operation: High for frequent emptying. **Institutional level:** Construction: Medium to high for fecal sludge collection and conveyance vehicles and treatment facilities. Operation: High for sludge collection, conveyance, and treatment.
	Double pit pour flush toilet ***Not recommended***	Smaller individual pits can be constructed incrementally, helping cash flow.	Toilet fixture, pit, and connecting pipework must be protected from freezing. Additional off-site sludge treatment is needed for safe reuse and disposal, negating advantages of double pits.	**User level:** Pits used alternately and periodically emptied when alternate pit is full. **Institutional level:** Operation and maintenance of communal elements of sanitation services (collection, conveyance, and treatment).	**User level:** Construction: Low to medium. Operation: Medium for emptying. **Institutional level:** Construction: Medium to high for fecal sludge collection and conveyance vehicles and treatment facilities. Operation: High for sludge collection, conveyance, and treatment.

Sanitation Type	Variations	Advantages of Use in Cold Regions	Disadvantages of Use in Cold Regions	Operational Requirements	Cost
Flush toilet with septic system ***Recommended for users with access to adequate water supplies who are willing to support the costs and effort of operating and maintaining such a system***		High level of service. Controls odors and insects and easy to keep clean. Location inside house is convenient and easy to use, especially for children and for people with limited mobility. Can handle greywater.	Medium to high water use required. Requires expert design and construction. All components, including underground components, must be protected from freezing. Poor maintenance leads to system failure.	**User level:** Periodic emptying. Freezing in any part of the system must be prevented. **Institutional level:** Operation and maintenance of communal elements of services (sludge collection, conveyance, and treatment).	**User level:** Construction: High to very high. Operation: Low to medium for periodic emptying. **Institutional level:** Construction: High for sludge treatment facilities. Operation: High for maintenance and operation of sludge treatment facilities.
Sewers ***Recommended for densely settled urban areas with adequate water supplies***		High level of service. Controls odors and insects and easy to keep clean. Location inside house is convenient and easy to use, especially for children and for people with limited mobility. Can handle greywater.	Medium to high water use essential. Requires expert design and construction. All underground components must be protected from freezing.	**User level:** Operation and maintenance of on-site components of system. Protect on-plot elements from freezing. **Institutional level:** Operation and maintenance of sewers and treatment facilities. Protect communal elements from freezing.	**User level:** Construction: Usually low to medium for connections. Operation: Medium sewage fee. **Institutional level:** Construction: Very high for sewer networks and treatment facilities. Operation: Very high for maintenance and operation of sewers and treatment facilities.

Table 3.2 Summary of Wet Sanitation Options

Note: lcd = liters per capita (person) per day.

Common Elements in On-Site Sanitation Systems

Superstructure

The superstructure, or shelter, houses the user interface and shelters the user, providing privacy and protection from the elements. Although not an element in the service chain, the superstructure and the user interface are important to the user experience. They are the components with which users have the most contact and can be used to indicate a family's status and prestige.

Improving the superstructure is a common way of upgrading an existing latrine. However, there is no point in constructing an improved superstructure on a badly built pit foundation or platform because it will be unstable and have a limited life.

The superstructure's form and materials depend on climate, affordability, material availability, user preference, and the type of toilet. If the superstructure does not need to be heated, it can be simple and cheap to build and maintain. It can consist simply of walls for privacy; it can be lightweight and movable, a more permanent freestanding structure, or a room in a house. Some people may prefer an outside superstructure away from the house, particularly for dry sanitation options, so that odors, flies, and other nuisances are less troublesome.

Photo 3.2 Latrine Superstructure, Ecuador
Source: World Bank.

Most superstructures are built at ground level, though they can be raised above ground level if it is difficult to dig a pit or if containers for receiving the excreta are located beneath the user interface. However, raised facilities must be equipped with stairs, which can cause difficulties for older or handicapped people. Photo 3.2 shows a typical latrine superstructure suitable for a cold climate.

User Interface

The term *user interface* in this report refers to the fixture used to capture excreta and isolate it from contact with the user—often called the toilet—and the slab or platform used to support it. The user interface can take a variety of forms suited for wet or dry sanitation. Slabs with holes or with toilet pans are for use when squatting, whereas pedestal toilets are designed for use when seated, which can be easier for the people with limited mobility. Toilets can be made of a variety of materials, from ceramics to wood.

The choice of user interface should depend on user preference and affordability, as well as the other elements of the sanitation system. Some toilet fixtures, with traps or water seals that reduce odors and control flies, are not suited for use with dry sanitation.

Users should select the interface carefully, without allowing their choice to be influenced by advertising, which can lead to choices that are unaffordable or inappropriate for their context. For example, some households surveyed in Mongolia wanted flush toilets outside the house—where the liquid in the toilet and pipes is likely to freeze in winter and block and damage both.

Examples of user interfaces are shown in photos 3.3 to 3.4 and include, among others, the following:

- A slab or platform over a pit with a hole for defecation made of wood, concrete, or other materials, sometimes with raised footrests
- A slab over a pit with a pan for defecation (the pan can be designed for use with or without water for flushing and to divert urine or not)
- A pedestal seat over a pit or connected to sewer pipes—the seat can be used with wet or dry sanitation and can be designed to separate feces and urine (often called urine diversion)
- A toilet seat over a bucket that collects excreta

Photo 3.4 Toilet Pan for Low-Flush Toilet for Use when Squatting

Source: © Eawag. Used with the permission of Eawag. Further permission required for reuse.

Photo 3.3 Examples of Toilet Pedestals for Use When Seated

Source: © Eawag. Used with the permission of Eawag. Further permission required for reuse.

As mentioned previously, toilets with water seals must usually be in a heated building. However, in some cases, the water seal in a pour flush toilet can be protected from freezing by filling the seal with an antifreeze solution that is lighter than water. The urine sinks below the antifreeze so it (and small amounts of water for flushing) pass through while the antifreeze remains in the toilet seal.

Containment

For on-site and hybrid sanitation systems, a pit, vault, tank, or container receives and temporarily or permanently contains the excreta after defecation. While contained, the excreta can be partially or fully treated by natural processes, such as decomposition or dehydration. The pit, tank, vault, container, or other receptacle is more important to the functioning of the facility than the user interface or the superstructure. The useful life of the facility depends in large part on the design and operation of the containment. A pit, tank, or vault located below a heated building is less likely to freeze than if it is offset, but it must be built at the same time as the building. It must also be designed and built to accommodate any movement of the soil as water in the pores freezes and thaws.

In dry sanitation options, excreta generally drop directly into the receptacle under the toilet. Common options for containment include the following:

- A pit, or hole, excavated into the ground. Solids are retained in the pit while liquids infiltrate into the surrounding soil. The pit can be lined, or partially lined in stable soils, with a variety of materials, from wood to masonry to concrete slabs. If the pit is fully lined, the lower portion of the lining should be porous. Lining pits can be expensive but can prevent collapse and facilitate emptying.
- A tank or chamber that has an inlet and outlet for liquid effluent but is otherwise watertight, such as a septic tank. It can be made of masonry, concrete, plastic, fiberglass, or other materials and built on-site or prefabricated. It may need to be anchored to prevent it from floating when empty. Solids settle out, and must be emptied periodically from the tank, while the effluent flows to a soakpit or infiltration field where it soaks into the soil or flows via sewer pipes to a wastewater treatment facility for treatment.
- A watertight vault, below or above the surface of the ground, without any outlet, sometimes called a holding tank. It is emptied when full, and its contents, which can include greywater, are taken to a treatment facility. Because a holding tank retains both liquid and solid waste, it fills more quickly than a pit or tank with porous walls or an outlet for liquids. It can be made of masonry, concrete, plastic, or other materials; it can be built-on site or prefabricated; and it may need to be anchored to prevent it from floating when empty.
- Smaller, movable containers for a container-based system. The containers are regularly removed and emptied for treatment off-site. Urine can be diverted and stored in containers or can infiltrate into the surrounding soil in a soakpit. Containers are often plastic but can be of other materials.
- Two pits or vaults, which are used sequentially. Commonly known as twin or double pits or vaults, they can be contiguous or not, and they can be built at the same time or separately. While one pit, tank, or vault is in use, the contents of the other are decomposing. When a pit or vault is full, it is closed; the other is emptied of its decomposed contents and put into use. The decomposed contents generally require additional treatment for safe reuse or disposal. The cycle of using and emptying the pits or vaults can continue for many years if they are used properly. Such pits are usually lined with masonry, concrete, or other materials to prevent collapse.

In all cases, containment should isolate the excreta to protect public health and the environment.

Emptying/Collection

Emptying, or collection, is when treated or untreated excreta, called sludge, are removed from the pit, tank, vault, or container where they have been deposited after defecation. It is difficult to remove sludge, so removal normally takes place in the warm season. In low-density areas served by simple pit latrines, it may be possible to dig a new pit once an existing pit latrine is full. The contents of the full pit should be covered with at least 0.5 meters of soil, then left in place without emptying, conveyance, or treatment.

Most sanitation systems, however, require periodic emptying, sometimes called desludging, to remove the accumulated sludge or wastewater. In areas where small plot sizes do not provide space for new latrines, full pits must be periodically emptied of the accumulated fecal sludge so the pits can be reused. Holding tanks, septic tanks, and leach pits or fields also require regular desludging. Failure to desludge septic tanks will cause the leach pit or field to fail. Container-based systems depend on regular removal of fresh fecal sludge. In most cases, households must arrange and pay for emptying of their facilities. Emptiers must have access to the pit, tank, or vault. In many places, emptiers must be licensed. In all cases, desludging requires care to avoid spreading excreta into the environment during the operation.

There are a variety of ways to remove sludge from sanitation facilities. Water-borne sewage can be collected in sewer pipes that lead to a septic tank or to a wastewater treatment plant. Low-viscosity sludge (sometimes called septage) from septic tanks or holding tanks can often be removed mechanically by tank trucks equipped with pumps. There are also manually operated sludge pumps for low-viscosity wastewater, such as the Sludge Gulper, developed by the London School of Hygiene and Tropical Medicine; the Manual Pit Emptying Technology (MAPET) developed by the nongovernmental organization (NGO) WASTE; and manually operated diaphragm pumps. These low-cost machines are usually small and can be used where access is restricted and trucks cannot enter. The pumps can often be made locally of available materials such as steel rods, valves, and PVC pipes and mounted on small carts with containers for the sludge (Tilley et al. 2014).

Thick, highly viscous sludge—for example, from latrine pits—can be more difficult to remove. If the superstructure and slab covering the pit can be moved so workers have access to the pit, sludge can be removed manually for transport to a treatment facility. In the cold season, workers can use compression hammers to break up frozen waste and remove it manually for conveyance. However, this is not recommended because spillage during manual removal can contaminate the environment and pose a risk to public health, especially for the workers handling the sludge. Removing the sludge with pumps can reduce these risks. Some manually operated pumps have been designed to empty thick sludge, such as the Nibbler, developed by the London School of Hygiene and Tropical Medicine. Motorized trash pumps and other pumps under development, such as pit screw augers, or the Gobbler or Vacutug truck-mounted systems, may also be able to remove highly viscous sludge. Like all mechanical options, they require expertise and spare parts to operate and maintain (Strande, Ronteltap, and Brdjanovic 2014).

In a container-based system, the user deposits excreta directly into a movable container, which, when full, can be collected on a truck or cart for conveyance. When the full container is removed from the household, a clean, empty container is put in its place. The haulers must have easy access to the location where the excreta are stored; this can be a problem in some areas, especially in winter. Collaboration between the household and the agency collecting and transporting the waste is required.

Conveyance

Conveyance is the transport of excreta or sludge from one place to another, generally in sewer pipes or by vehicle. Waste can be conveyed from the point where it has been generated, to an intermediate facility for containment, directly to a facility for treatment, or to a final disposal point.

Photo 3.5 Insulated Vacuum Truck

Source: © GV Jones & Associates, Inc. Used with the permission of GV Jones & Associates, Inc.

Vacuum tankers, like that shown in photo 3.5, are common in many places and are suited to conveying large volumes of mainly liquid waste—for example, sludge from septic tanks. High-viscosity waste, such as sludge from pit latriYnes, may be better suited to other types of vehicles. In a container-based system, the full containers themselves are transported to a facility for treatment or disposal.

Haul systems, including container-based sanitation, have a high capital and operational cost, so they may not be financially sustainable without subsidies (GV Jones & Associates, Inc. 2015a). However, these costs may be lower than the costs of building and operating sewers, which are also high, particularly in cold regions, and are often also subsidized.

A major risk with haul systems is that haulers will not take the waste for treatment or disposal but will deposit it in a nearby water body or on empty land. This is especially likely if the haulers must pay to deposit the waste at treatment facilities or if the facilities are far from the point where the hauler collects the sludge. Use of intermediate containment facilities can reduce distances for haulers but must be emptied regularly and maintained well—and it can be difficult to find convenient sites that are acceptable to nearby residents (Strande, Ronteltap, and Brdjanovic 2014). Also, it can be difficult or impossible to remove frozen waste from intermediate containment facilities because they would need to be large enough to accommodate all the waste discharged in the entire cold season.

Treatment

The objective of treatment is to convert fecal sludge into inoffensive materials that do not pose a risk to public health or the environment and that are inoffensive and easy to handle. Untreated human excreta contain a high organic load, including pathogens, nitrogen, and other chemicals, so they require treatment to protect human health and the environment (Strande, Ronteltap, and Brdjanovic 2014).

In selecting a treatment method, considerations include the quantity and characteristics of the waste; costs and affordability; the availability of technical skills, materials, and spare parts for operation and maintenance; and requirements for land and electrical power; among others. The required degree of treatment depends on the end use or disposal method of the treated waste. For example, reuse on food crops requires a high degree of treatment to ensure that pathogen concentrations are reduced to levels that are safe for workers and consumers. If treated wastewater is to be discharged to a water body, the degree of treatment required depends on the potential dilution of the wastewater in the water body and on the likelihood that people will come into contact with the water downstream of the discharge point (Strande, Ronteltap, and Brdjanovic 2014).

Converting fecal sludge into a material, or product, that is safe for reuse or disposal often requires several steps. Treatment for fecal sludge can be mechanical or physical, biological or chemical, or some combination of these:

- Common physical mechanisms include dewatering and drying, which reduce moisture content and volume. Methods include gravity separation or settling, screening, filtration, evaporation and evapotranspiration, centrifugal force, pressure, and heat drying. Freezing and thawing can facilitate dewatering.
- Biological mechanisms transform organic constituents, nutrients, and pathogens when microorganisms degrade or decompose the sludge. Biologic treatment methods include composting and other types of aerobic or anaerobic digestion.

- Chemical mechanisms are mainly used for disinfection and to enhance dewatering. Methods usually involve mixing chemicals such as lime, ammonia, or urea with the sludge but also include the chlorination of liquid effluent (Strande, Ronteltap, and Brdjanovic 2014).

Research and development for fecal sludge treatment is ongoing, but some common treatment processes for sludge from on-site sanitation are co-treatment at a sewage treatment plant or waste stabilization ponds and disposal at a sanitary landfill or on drying beds, where the sludge is dehydrated and stored until safe to handle. Many common processes use natural processes over time as the main treatment method.

Composting

There is growing interest in composting excreta so that the nutrients they contain are preserved, an approach called EcoSan (ecological sanitation). Composting treats the sludge through decomposition, a natural biological process, which produces an inoffensive humus that can be reused as a soil conditioner or fertilizer. Normally, the latrine is built above ground level to facilitate emptying; the excreta drop into a vault or container. After defecation, the user adds leaves, sawdust, or other organic material to enhance decomposition. Urine diversion can help control odors, but urine contains many of the plant nutrients found in excreta, so humus made from urine and feces has a higher nutrient content than humus made with feces alone. Urine can also be used on its own as a fertilizer.

Composting toilets are generally more expensive and complex than pit latrines to build and operate (World Bank 2008). Therefore, composting toilets are most likely to succeed when people want to use the treated excreta, understand the technology, and are willing to manage it correctly.

In principle, the sludge can decompose in the toilet facility or be removed for treatment elsewhere. However, decomposition depends on the temperature, moisture content, carbon-nitrogen ratio, degree of aeration, pH level, and physical structure of the raw materials, which can be complex to manage. In hot composting, these factors are carefully monitored and adjusted so that the sludge reaches temperatures that will inactivate pathogens, sanitizing the sludge (Ryndin and Tuuguu 2015).

Composting may be better suited to container-based sanitation systems than to on-site facilities because reaching the temperatures required to sanitize the excreta and fully inactivate the pathogens is extremely difficult at the household level, especially in cold climates. Therefore, sludge from household latrines will need further off-site treatment for sanitization and safe reuse. The need for off-site treatment negates the potential advantage of on-site treatment—namely, that there should be no need for emptying, collection, conveyance, or further treatment.

At larger scales, sludge generated during the cold season can be stored and then composted during the warm season (Seefeldt 2011). During winter, it can be difficult for compost to reach the temperatures needed for sanitization without adding heat, which is costly. However, the composting facility must have sufficient capacity to compost, during the warm months, all the excreta collected during the entire year. Sufficient storage for the untreated sludge generated during the cold season is also required.

Co-composting sewage sludge from wastewater treatment plants may be an option in some areas because larger volumes of sludge can more easily reach the temperatures required to sanitize sludge. In Fairbanks, Alaska (Utility Services of Alaska, Inc. 2016), and Edmonton, Canada (City of Edmonton 2017), both of which are in cold regions, treated sewage sludge is successfully co-composted with other organic waste year-round. The sale of the humus, or compost, helps cover treatment costs.

Wastewater Treatment Lagoons

Sometimes called waste stabilization ponds, wastewater treatment lagoons are manmade water bodies that can be used individually or linked in a series to improve treatment (Tilley et al. 2014). High-viscosity wastewater such as sewage, septage, or effluent from septic systems can be treated in these ponds, and fecal sludge from latrines can be co-treated with this more liquid waste (Strande, Ronteltap, and Brdjanovic 2014). Lagoons can be more expensive to build than secondary sewage treatment plants, but operation and maintenance expenses are lower, they are simpler to operate, and they provide adequate, stable treatment (Schubert and Heintzman 1994). In addition to routine maintenance, they must be desludged periodically, and the sludge—which still contains pathogens and nutrients, though less than raw fecal sludge—must be safely disposed of. In general, lagoons require a large land area away from residential areas and from water sources used for human consumption.

Wastewater lagoons have been the most common method of wastewater treatment and disposal for communities with water supply and sewer systems in extremely cold environments in rural Alaska. All treatment occurs during the warm season, and the treated wastewater is released at the end of the warm season. Some designers recommend two lagoons, used alternately, to ensure adequate treatment (Tilsworth 1972). Lagoons must be large enough for all the wastewater generated during the cold season.

Drying Beds

Sludge can be treated on planted or unplanted drying beds. The latter may be more suitable in very cold climates where plants might not survive the cold season. Drying beds are relatively inexpensive and simple to use, but they can require large land areas. Unplanted drying beds are effective for dewatering, whereas planted drying beds can also provide a degree of treatment (Strande, Ronteltap, and Brdjanovic 2014).

Constructed Wetlands

Planted constructed wetlands, which treat wastewater that has already undergone primary treatment, have been used successfully in cold regions (ARM Group Ltd. n.d.). However, their performance in extremely cold climates remains in question (Mæhlum, Jenssen, and Warner 1995). Concerns at low operating temperatures include ice formation, low reaction rates, and dormant vegetation.

Deep Row Entrenchment

Deep row entrenchment can be used to treat and dispose of sludge, which is deposited in deep trenches. When the trench is full, the sludge is covered with soil and trees are planted on top. Deep row trenches are inexpensive and simple to build and operate but require relatively large amounts of land and safe separation distances from groundwater and residential areas. They have been used for sewage sludge in the United States and for fecal sludge in Durban, South Africa, and could be piloted in cold regions.

Other Treatment Methods

In warm climates, sludge can be treated by biodigestion in a domed or geobag type biodigester, which is meant to produce biogas for energy. However, biodigesters are not generally suited to cold climates because, at temperatures below 5°**C**, the production of gas is negligible. Furthermore, sludge removed from the biodigester requires additional treatment because it is likely to contain pathogens.

Other innovative fecal sludge treatment methods in development include the following (Strande, Ronteltap, and Brdjanovic 2014):

- Vermicomposting—that is, treatment with earthworms
- Treatment by the larvae of black soldier flies—the larvae can be used for poultry or fish food
- Pelletizing, for example in the latrine dehydration and pasteurization (LaDePa) process
- Treatment with ammonia or urea, thermal drying, and pelletizing
- Solar drying

However, these approaches are unproven for use in cold climates, with the possible exception of treatment with ammonia and urea (Nordin, Nyberg, and Vinnerås 2009).

It may be possible to adapt processes used to treat sewage sludge to treat fecal sludge—for instance, anaerobic digestion, Imhoff tanks, sludge incineration, lime addition, and mechanical treatments, such as centrifuges and presses. However, these technologies have not yet seen wide use for treating fecal sludge, and they may not be cost-effective or affordable for low-income countries, especially in cold regions.

End Use/Disposal

Untreated sludge or blackwater has been used in agriculture and in aquaculture in parts of Asia and Africa, but it is not recommended because it poses high risks to human health. Discharge of untreated wastewater onto land or into water bodies can also pose a risk to the environment as well as to human health. Sewage may be discharged into water bodies if the dilution and dispersal of the waste is adequate, but this requires careful study to protect public health and the environment.

Treatment/Goal			End Product/End Use
Solid/Liquid Separation	Dewatering	Stabilization/Further Treatment	
Imhoff tanks Settling/thickening tanks	Mechanical dewatering Unplanted drying beds	Co-composting Deep row entrenchment Lime/ammonia addition Sludge incineration Anaerobic digestion Vermicomposting/ black soldier flies	Soil conditioner Irrigation Proteins Fodder and plants Building material Biofuels
	LaDePa pelletizing machine Thermal drying Solar drying Planted drying beds		
		Co-treatment with wastewater	

Figure 3.1 Possible Sludge Treatment Technologies and End Uses

Source: Adopted from Strande, Ronteltap, and Brdjanovic 2014.

Note: LaDePa = latrine dehydration and pasteurization.

Adequately treated waste, however, can be safely reused as a source of plant nutrients, as mentioned in the previous section on waste treatment. There is also increased interest in the use of energy from human waste, including the production of biofuels from fecal sludge (Strande, Ronteltap, and Brdjanovic 2014). In warmer climates, pilot projects have used excreta to make fuel briquettes, which may be worth exploring in cold regions. In Japan and China, sludge is incinerated to produce cement (Strande, Ronteltap, and Brdjanovic 2014). Dried excreta have also been used in building materials because dried sludge has similar qualities to some traditional materials such as clay and limestone. Other applications in ceramics and in cement production are being tested (Strande, Ronteltap, and Brdjanovic 2014). The World Health Organization (WHO) provides parameters for the safe reuse of wastewater and excreta, including urine and composted or treated feces or excreta (WHO 2006). Figure 3.1 shows examples of potential products from fecal sludge and the technologies that can produce them. However, some of the treatment methods may not be suited to use in cold regions.

Improved Simple Pit Latrines

Improved simple pit latrines are the recommended option for many households in cold regions. They can be an acceptable option to protect human health and the environment, including the improvement of existing latrines. Pit latrines are well-suited to use in cold climates, though they may be cold in winter. Pit latrines do not function very differently in cold climates than in warmer ones. A typical simple pit latrine is shown in figure 3.2.

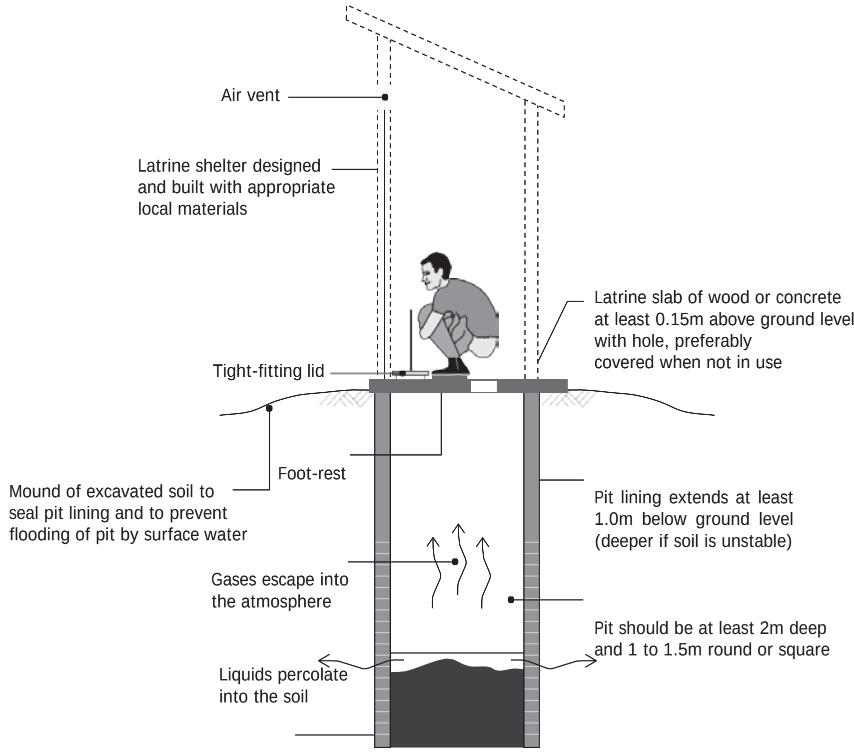

Figure 3.2 Improved Simple Pit Latrine

Source: Adapted from WEDC, Loughborough University.

Simple pit latrines normally consist of a user interface, covered by a superstructure, over a pit that receives and contains the solid portion of the excreta while the liquid portion infiltrates into the soil. They are familiar to many users; they are simple and inexpensive to build and maintain; and they function well in a cold climate. As a dry option, simple pit latrines are suitable for use in areas where choices are limited by low water availability, though they can also be used where more water is available.

The pits can be closed and abandoned when full, or they can be emptied and the contents conveyed to a treatment facility. The walls of pits that will be emptied, or of pits excavated in unstable soils, should be lined to prevent collapse. The pit should be accessible to emptiers if emptying is needed. However, because the liquid seeps into the ground, the fecal sludge is often quite viscous and difficult to empty.

Pit latrines need not be unpleasant; a well-built and well-maintained latrine can provide a good user experience. However, it can be difficult to overcome the idea that latrines are smelly, dirty, disgusting places that pollute their surroundings. In fact, many latrines are unpleasant, with unsteady platforms over pits that may have partially collapsed and a poor-quality superstructure, so this idea persists.

Normally, a pit latrine will be located outside, at some distance from the home, in a freestanding superstructure that provides privacy and shelter for users. The roof of the superstructure should overhang the walls so that meltwater running off the roof does not run down the walls but rather falls away from them. The latrine floor or slab, also called a platform, covers the pit and supports the user and the toilet and other fixtures. The slab should cover the entire pit, be easy to keep clean, and be solid so that the user feels safe while using it.

A pit latrine has the major advantage of allowing users to make small incremental improvements to their latrine over time, gradually making it more comfortable and agreeable, as their finances and wishes allow, without needing a major capital investment. Photos 3.6 to 3.8 show examples.

Photo 3.6 Unimproved Basic Pit Latrine
Source: World Bank.

Possibilities for improving a pit latrine include the following:

- If the latrine floor is wood, add a layer of concrete mortar, sloped slightly down toward the defecation hole, so the surface is easy to clean, without cracks.
- Add footrests to support the user when squatting.
- Add a squatting pan made of easy-to-clean, appealing materials to improve the user experience and make the toilet easier to clean.
- Add a pedestal seat, if the users prefer to sit, made of—or covered with—materials that are easy to clean and suitable for use in cold temperatures.
- Add a urine-diverting toilet or squatting pan, can reduce odors—but must be designed so that the urine does not freeze and block the toilet.
- If the toilet enclosure is heated, add a water seal pan or seat to reduce odors and flies.
- Add a tight-fitting lid to the defecation hole or toilet seat to reduce flies and odor.
- Improve the superstructure by adding a smooth surface, such as ceramic tiles or other appealing easy to clean materials to the floors and/or walls.
- Slope floors slightly toward the defecation hole for easy cleaning.
- Raise the latrine floor or slab at least 15 cm above ground level and slope the soil away from the latrine so that surface water cannot enter the pit and erode and weaken the pit walls.
- Seal the latrine slab to the pit walls so that there are no cracks between the top of the pit and the superstructure, thus reducing odors and flies.
- Add a ventilation pipe to help reduce odors, with a screen on the upper end to reduce flies.
- If the toilet enclosure is heated, add a device, such as a basin with water, for handwashing (if the toilet enclosure is not heated, facilities for handwashing should be provided elsewhere).

Photo 3.7 Pit Latrine with Improved Slab
Source: World Bank.

Photo 3.8 Pit Latrine with Improved User Interface
Source: © GV Jones & Associates, Inc. Used with the permission of GV Jones & Associates, Inc.

- Provide a mechanism to ensure easy access to the latrine pit for emptying.

Depending on the users' preferences, and the context, other improvements may be possible. Marketing research can help determine users' preferences and priorities, as well as their willingness to invest in each of the potential improvements.

When users think of upgrading a latrine, they often think about upgrading the above-ground part of the latrine to improve the user experience. However, upgrading the pit by lining the walls can make it easier to empty, make it less likely to collapse, and extend the life of the latrine. A latrine with a wood-lined pit is shown in figure 3.3.

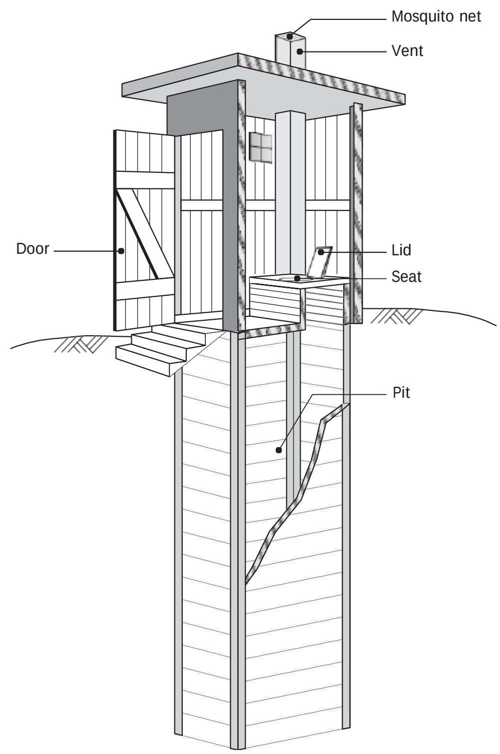

Figure 3.3 Pit Latrine with Wooden Pit Lining

Source: © GV Jones & Associates, Inc. Used with the permission of GV Jones & Associates, Inc.

Round pits tend to be more stable and less likely to collapse than square or rectangular pits. They are also more economical because they use fewer materials to construct per unit of volume. Pits should be at least 1.2 to 1.5 meters in diameter or width or else they will be difficult to dig. The walls of the pit can be unlined or lined. In most cases, the top 0.5 meter of the pit walls should be lined and impermeable. If the soil is unstable and likely to collapse, the entire pit should be lined. The lining of the lower part of the pit should be porous to allow infiltration of liquid into the surrounding soils. The lining can be made from a variety of materials. Wood is flexible and can accommodate some soil movement; however, it may not be as durable as materials such as masonry or concrete blocks. Metal linings will corrode quickly, and clay bricks may crumble quickly in cold conditions, so unproven materials should be tested before use.

Where the latrine's expected life span is short, a movable support, such as a concrete ring beam resting on the ground around the top of the pit, can be used to support the slab and users and to prevent water from entering the pit.

The pit volume, which will need to be larger in cold climates than in more moderate ones, should be calculated according to the number of users and the desired life of the pit before it fills. Excreta production globally ranges from about 200 to 500 grams of feces per person per day and 0.6 to 1.1 liters of urine per person per day (Franceys, Pickford, and Reed 1992). The amount will vary with diet and other factors, so it should be determined locally. However, using an estimated total production of 1.25 liters of urine and feces per user per day, a household of four might be expected to produce 5 liters per day of excreta. If the ground is frozen for four months—that is, about 120 days—then the expected household accumulation over the cold season would be about 600 liters. Thus, the pit would need at least 0.6 cubic meters of empty space at the beginning of the cold season to accommodate the excreta generated during that time. A shared latrine with eight users would need about 1.2 cubic meters of space at the start of the cold season for excreta alone. Over time, as the excreta break down and liquid filters into the ground, the expected accumulation is about 60 liters per person per year (Franceys, Pickford, and Reed 1992).

In many places, such as several states in the United States, regulations require at least 31 meters of horizontal separation between a leach pit and a lake, river, or private well and 62 meters to a public well. The bottom of the pit should be 1.5 to 2.0 meters vertically above the groundwater table. These distances may be decreased for some advanced on-site water treatment systems or increased where fractured or jointed bedrock is within 2.0 meters of the surface of the ground where the latrine is sited (InspectAPedia 2017a). Many sources also recommend at least six meters of separation between cooking or residential areas and pit latrines. When possible, groundwater should flow from any water source toward the pit, not from the pit toward the source, to avoid contamination of the water source.

Pits for simple pit latrines may be difficult to excavate in areas where bedrock or the water table is near the surface. In those cases, other options, such a raised pit latrine, can be considered. More information about raised pit latrines is given in a later section.

In cold climates, sludge removed from latrine pits always requires additional treatment before it can be considered safe for reuse or disposal. Decomposition is slower, and decomposing excreta will generally not reach the temperatures required to sanitize the sludge, even in composting toilets. Pathogens are likely to persist longer than in warmer climates because many microorganisms can survive freezing conditions. They become dormant or convert to spores or cysts, which revive in warmer conditions.

Operational/Maintenance Requirements

Household Level

Pit latrines are likely to be familiar to users in cold regions. However, users may need training if they choose urine-diverting dry toilets (UDDTs) as their user interface or other unfamiliar technologies.

When a latrine pit is full, users have two choices: (a) cover the excreta with soil and close the pit and build a new latrine or (b) empty the full pit and reuse it. Households are generally responsible for emptying the pit or arranging and paying for it to be emptied. Pits can be emptied by manual labor or by mechanical means such as a vacuum truck. In general, sludge from pit latrines will be quite viscous and better suited to manual emptying. However, it may be possible to add liquid to the sludge to liquify it for mechanical emptying. Emptying must be done with care because the pit can collapse when empty. Also, spills or leaks can endanger the environment or human health, including the health of workers who empty latrines.

Users can add materials, such as leaves, ashes, or sawdust, to the pit after defecation to help control odors and insects. However, the amount should be moderate because a large amount of inert material can hamper further treatment, such as composting or treatment in a sewage or sludge treatment plant. Also, ashes tend to solidify the contents and make them more difficult to empty mechanically.

Only soft paper should be put into the pit. Other anal cleansing materials can fill the pit quickly and interfere with the emptying and treatment of waste. Users need to safely store and dispose of anal cleansing materials that are not put into the pit because they can pose a risk to public health and the environment. Users should not use latrines for disposal of trash, especially nonorganic waste, such as batteries, glass, plastic or metal containers, clothing, or other items. The trash will fill the pit quickly and make it more difficult to empty, especially by vacuum truck. Also, if chemicals are put into the pit, they can seep into the ground and pollute the groundwater.

Institutional Level

Local authorities must manage sludge emptied from latrines because it is rarely, if ever, safe for reuse or disposal in the environment without additional treatment and sanitization. Even if it is emptied by private sector entities, the government must regulate them. Authorities must ensure that facilities for safe treatment, disposal, or end use are available and correctly used. They must ensure that institutional and regulatory frameworks are appropriate and practical—and enforce the regulations.

Local authorities can also promote latrine improvements and build demonstration latrines to show that latrines can be clean, comfortable, and attractive—without flies or odors—at a low or moderate cost.

Practical Experience in Cold Regions

Pit latrines are common around the world, in cold areas as well as warm ones. However, as mentioned earlier, many latrines smell bad and breed vectors and vermin because they are poorly sited, designed, constructed, used, and maintained. The consequent negative image can be difficult to change.

Other Requirements

Pit latrines require no water or added energy to function. Users who would like the latrine to be lit at night could explore the use of solar lanterns.

A pit latrine does not normally require more than 4 or 5 square meters of space. However, if the household chooses to close the latrine and build a new one when the latrine pit is full, eventually, the requirements for space will be quite large as more replacement latrines are needed.

Greywater Disposal

Most pit latrines can handle only small amounts of greywater. However, in the winter, when the soil is frozen and liquid cannot infiltrate into the ground, users must take care not to exceed the capacity of the pit. Grease, fats, and oil should not be put into the pit because they clog the pores in the soil and reduce its capacity to absorb liquid from the pit.

Potential for Reuse of Excreta

Decomposed excreta from pit latrines can potentially be reused. However, they are not safe for reuse, especially in agriculture, without further treatment (Strande, Ronteltap, and Brdjanovic 2014). Moreover, as mentioned earlier, stabilization and sanitization of excreta will generally take longer in cold regions than in warmer ones. Also, users are often reluctant to handle and reuse the decomposed excreta, even after it has degraded into an inoffensive, soil-like material.

In cold regions, it might be interesting to explore the use of excreta to make fuel pellets, which is being explored in warmer countries. Also, in places where there is sunlight on most winter days, solar energy may be useful for adding heat to facilitate sludge treatment as well as for lighting sanitation facilities.

Expected Life

The life of a pit latrine usually depends on the amount of time that it takes for the pit to fill and on whether it can and will be emptied. Thus, it depends on the number and type of users. Also, if trash—especially nonorganic trash such as plastics—is put into the latrine pit, it will fill faster, and emptying will be more difficult. The type of anal cleansing material will also have an effect if those materials are put into the pit.

A well-designed, well-constructed, and well-maintained latrine with a pit that is emptied periodically and lined with masonry, and with a concrete slab, can last for decades. However, the gases in a latrine pit are corrosive and can corrode some materials, especially metal, potentially shortening the life of the latrine. Also, unlined pits can collapse when emptied.

Decomposition reduces the volume of the excreta in the pit over time, so a larger pit lasts longer in relation to its size. That is, normally, a pit twice as large as another pit will last more than twice as long as the smaller pit. Thus, a very large, deep pit can last for many years even without being emptied, thanks to the breakdown of the excreta. However, as mentioned earlier, breakdown will take longer in cold climates—the rate varies with the length and severity of the cold season.

Expected Costs

Capital Costs

Construction costs for a basic pit latrine vary depending on the materials and other variables but can be very low, particularly if the household constructs its own latrine. The costs of improving an existing latrine can be spread over time if the household upgrades the latrine incrementally. If pits are not emptied, however, some costs can be expected each time a new latrine is built to replace a full one. Lining the pit can add substantially to the initial cost of the latrine. However, this can be cost-effective in the long run if pits must be emptied because the lining should prevent pit collapse and prolong the life of the latrine, especially if durable materials such as masonry are used.

Construction of a pit latrine, with a wooden pit lining, slab, and superstructure, was estimated at about US$300 in Mongolia in 2014 (GV Jones & Associates, Inc. 2015b). The World Bank estimated that in 2006 in Mongolia, a simple pit latrine with a pit lined with stone masonry, a wooden slab, and a superstructure of wood and masonry would cost US$95 to $130 (Community-Led Infrastructure Development Project 2006). The World Bank estimated that in 2016 in the Kyrgyz Republic, the costs of a pit latrine with a partially lined pit, a concrete slab, ventilation pipe, and brick superstructure was about US$200, whereas an improved version with lighting, a tiled floor, and a ceramic pedestal toilet was about US$360.

Operation and Maintenance Costs

The maintenance costs for a pit latrine relate mostly to the cost of emptying the latrine. Emptying can be by vacuum truck during summer months or by manual emptying in summer or winter. As an example, estimated costs in 2014 in Ulaanbaatar, Mongolia, were about US$26 for mechanical emptying and about US$43 for manual emptying (Roger 2015). These can be significant costs for many households.

Other Advantages/Disadvantages

Poorly sited and constructed latrines can pollute groundwater around the pit, especially in areas of high groundwater. The extent of the pollution depends in large part on the hydrogeological characteristics of the area. As a rule, wells within 30 meters of pit latrines should not be used for human consumption without testing for contamination; this distance should be increased to 200 meters or more if the latrines and wells are sited in fractured bedrock (InspectApedia 2017b).

Seasonal runoff can flood latrines and pollute the surface water and soil around the pits if the latrines are not properly sited, designed, constructed, or maintained.

Variations

Pit latrines can be varied in many ways. They can be constructed with a single pit, a double pit, or a single or double raised pit. The pits can be ventilated, or the urine can be diverted.

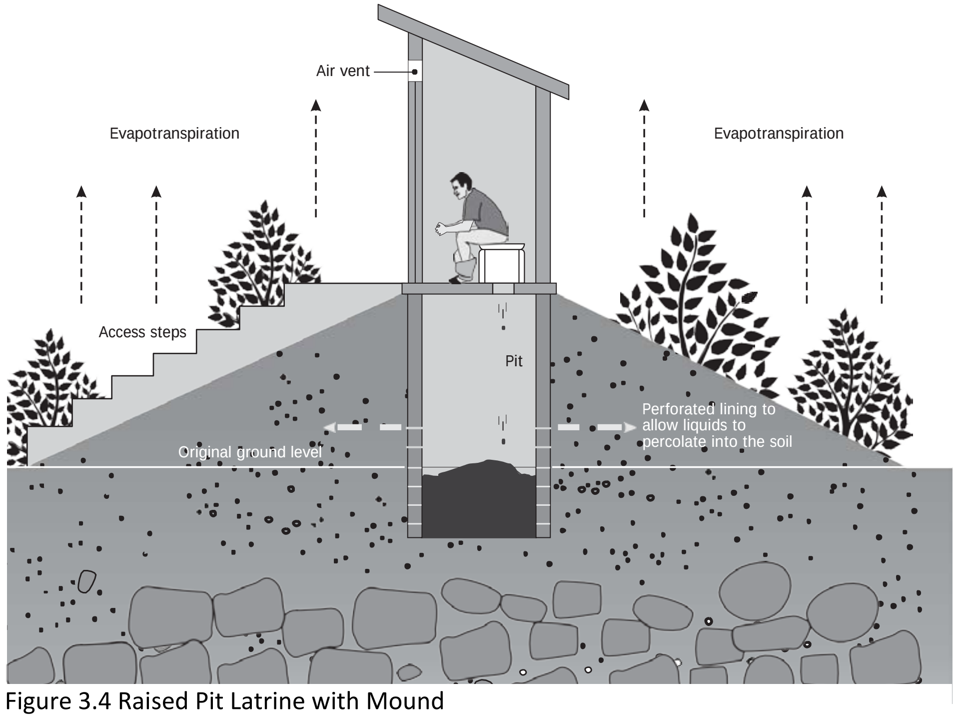

Figure 3.4 Raised Pit Latrine with Mound

Source: Adapted from WEDC, Loughborough University.

Raised Pit Latrine

Raised pit latrines may be suitable for areas prone to flooding or where the water table or the bedrock is close to the ground surface, making it difficult to dig a pit.

This latrine is similar to a simple pit latrine except that the pit is raised wholly or partially above ground. The above-ground part consists of walls, normally made of masonry or concrete, that can be surrounded by a built-up mound of soil. The pit can extend below ground level, though it normally does not extend as deeply into the ground as a simple pit latrine. This can help maintain the required vertical separation between the bottom of the pit and the groundwater, reducing the risk of polluting the groundwater, as shown in figures 3.4 to 3.5.

Cold climate considerations are much the same as for a simple pit latrine except that the materials in an above-ground pit can be expected to freeze and thaw more quickly than the contents of an in-ground pit.

For additional details, see the previous section on improved simple pit latrines.

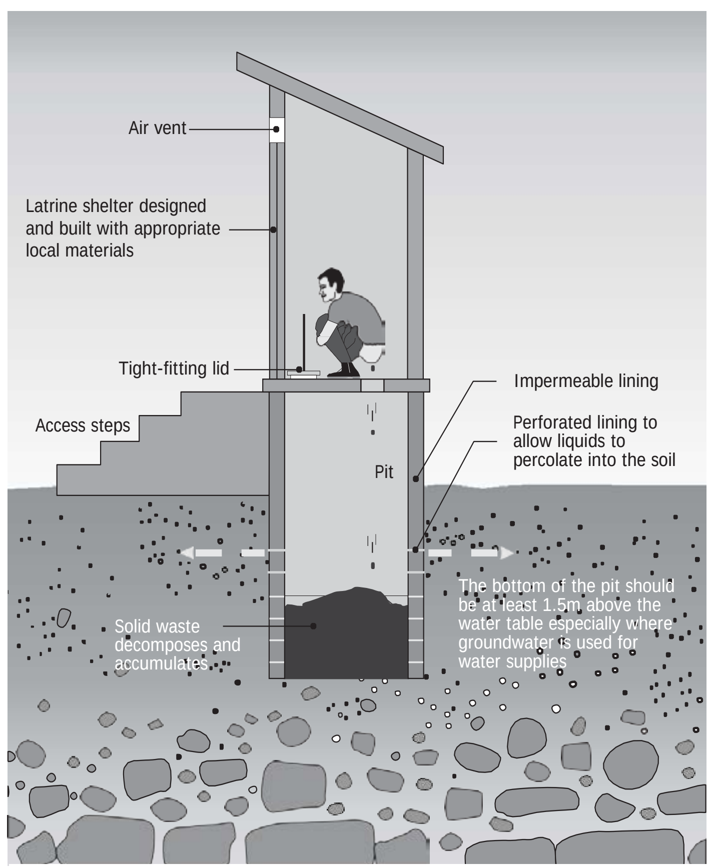

Figure 3.5 Raised Pit Latrine

Source: Adapted from WEDC, Loughborough University.

Arborloo

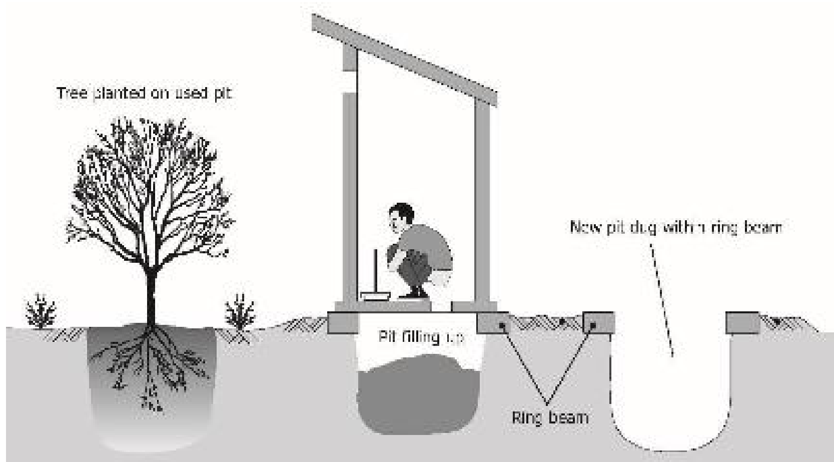

Figure 3.6 Arborloo
Source: Morgan 2007.

An arborloo is a version of a simple pit latrine with a relatively shallow unlined pit. It has a movable cabin that rests on a ring beam or other support that can also be moved, as shown in figure 3.6. Because the pit will be used for a relatively short time, it does not need to be lined. When the pit fills, the cabin and the ring beam are moved to another site with a new pit. The full pit is covered with soil, and a tree is planted on top of it (Tilley et al. 2014). This type of latrine is best where there is enough space for replacement latrines and for trees. However, such latrines would have to be tested to see whether the heaping of frozen excreta prevents the use of shallow pits and whether people would like to plant trees near their homes.

VIP Latrine

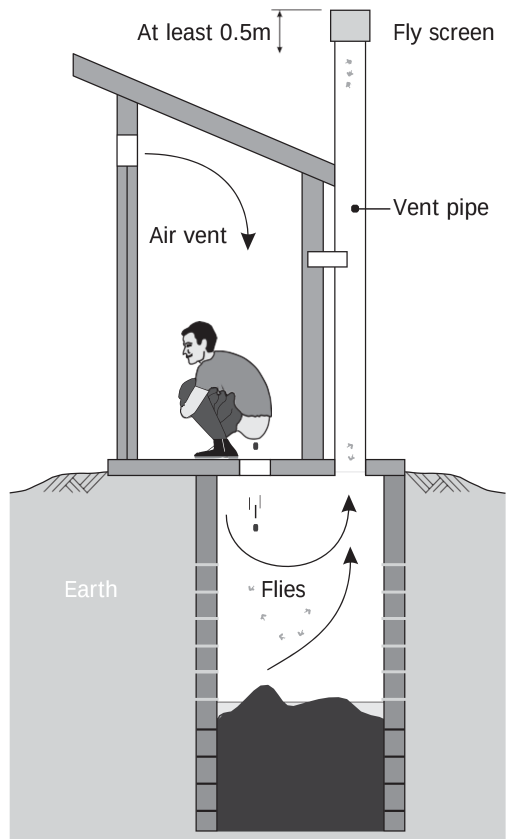

Figure 3.7 Typical Ventilated Improved Pit Latrine
Source: Adapted from WEDC, Loughborough University.

Ventilated improved pit (VIP) latrines are not recommended but are included here because there is often demand for them. In practice, VIP latrines are rarely built properly; thus, they do not function correctly. Also, many users, especially children, don't like the dark superstructure. VIP latrines can be recommended only if designers, builders, and users understand and accept the proper way to design, build, and use them, which is rarely the case. Although there should be little harm equipping a simple pit latrine with a ventilation pipe—other than the additional cost—it will not control odors or flies effectively if the design and construction do not meet the other requirements for a VIP latrine.

In a properly built and operated VIP latrine, odors are reduced because the air that enters the superstructure passes into the pit through the seat or defecation hole, then out of the pit through the ventilation pipe, and exits the end of the pipe above the latrine. Air with odors from the pit does not enter the cabin.

Because the cabin is kept dark, the flies in the pit are attracted to the light at the top of the ventilation pipe. They fly up the pipe toward the light, but the screen at the end of the pipe keeps them inside the pipe, where they die. A typical VIP latrine is shown in figure 3.7.

The vent pipe should be kept clear of cobwebs or other obstructions. The screen at the top of the pipe must be kept clean and free of ice and snow. It should be inspected regularly and replaced as needed, especially metal screens, which are subject to oxidation from the latrine gases. Although screen maintenance is important for controlling flies, it is often neglected.

Cold climate considerations include most of the same considerations as for a simple pit latrine—see the section on improved pit latrines for details. Additional considerations include the following:

- Although cold ground temperatures will freeze the contents of any unheated pit, the induced air flow through a ventilated pit will cool the pit contents and cause the waste to freeze more quickly than in an unventilated pit (GV Jones & Associates, Inc. 2015e).
- VIP ventilation systems do not work well in still air, particularly if the air is colder than the pit contents. These conditions can induce a reverse air flow—through the pipe into the pit and out into the cabin—increasing odors in the superstructure (Reed 2014).

Double Pit Latrine

Double pit latrines consist of latrines with two pits that are used in turn, emptied, and used again, over and over, as shown in figure 3.8. While one pit is in use, the excreta in the other decompose into an earth-like material called humus. This cycle can continue over many years if the latrines are well maintained. Even in warmer climates, however, people are not likely to be willing to enter the pit to empty it. They may also be unwilling to reuse the humus as a fertilizer or soil conditioner.

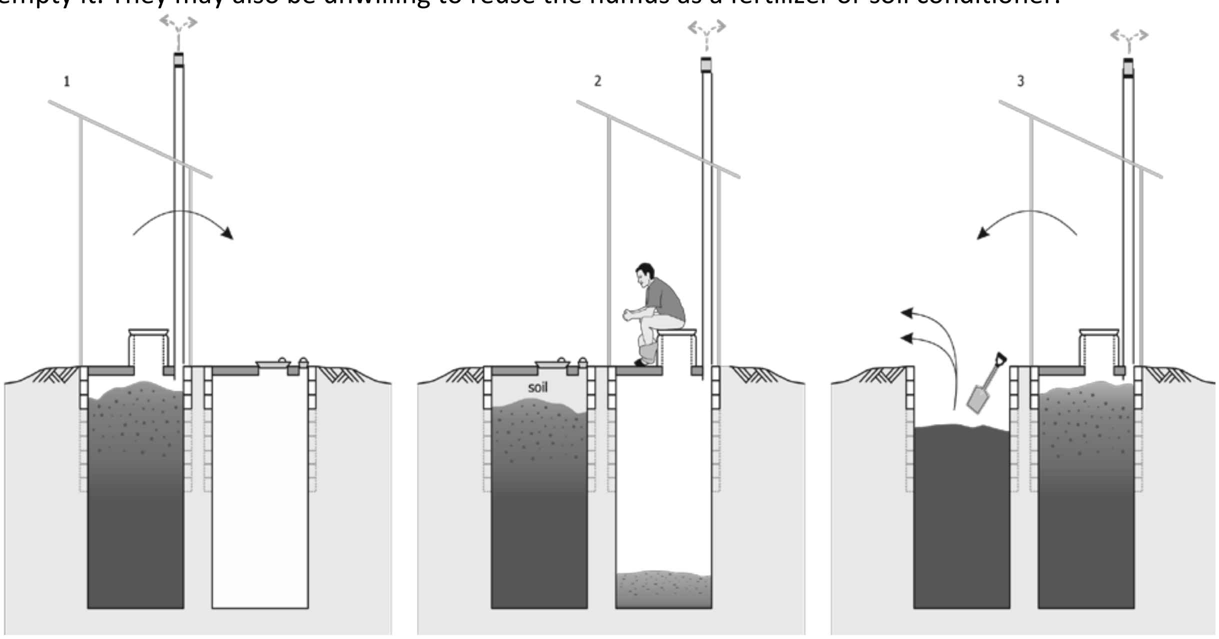

Figure 3.8 Double Pit Latrine

Source: © Eawag. Used with the permission of Eawag. Further permission required for reuse.

Double pit latrines cannot be recommended for use in cold regions. The humus may contain pathogens and cannot be reused unless (a) it is tested to ensure that it is free of pathogens or (b) it undergoes additional treatment before disposal or reuse. The costs for testing or for conveyance and additional treatment may make this option unattractive in cold regions, where it is likely to have few, if any, advantages over container-based sanitation.

Container-Based Sanitation

Container-based sanitation involves the collection of excreta in containers and conveyance of the full container from the household to a central facility for treatment. Urine can be allowed to soak into the ground, collected separately, or mixed with the feces. Although technically feasible in cold regions, this system cannot succeed unless there is an organization that will collect and treat the latrine sludge on a regular basis. Considerable logistical capacity is required to reliably collect and convey the excreta. Effective and appropriate institutional, regulatory, and financial frameworks are also required.

Container-based sanitation may be a cost-effective alternative to conventional water-borne sewerage. However, governments that have supported conventional sewerage, for example by subsidizing capital costs, may insist that users pay the full cost of container-based sanitation without government assistance.

The on-site toilet facility often consists of a UDDT. As shown in photo 3.9, the toilet fixture is positioned above a removable container. The feces drop directly into the container. The urine either soaks into a pit in the ground or is collected in a separate container. The urine diversion pipes must be carefully designed to function in winter. If the pipe diameter is too small, or if the pipe slope is too flat, the urine will freeze and block the pipe. It is possible to mix the urine and feces in the same container, but the containers will fill more quickly and be heavier to handle and convey.

Photo 3.9 Container-Based Sanitation with Urine-Diverting Dry Latrine, Mongolia

Source: World Bank.

Periodically, the full containers are collected and replaced with clean, empty containers. The full containers are conveyed by vehicle to a facility where the feces and urine are removed from the containers, treated, and reused or disposed of, and then the containers are cleaned. Ideally, the fecal sludge will be treated to produce sanitized humus, or compost, which can be reused as a soil conditioner or fertilizer.

Raised superstructures provide space for containers under the toilet, but they may cause difficulties for users whose mobility is impaired. The superstructure can also be built with containers in a pit and the user interface and floor at ground level. However, in this case, it may be difficult to retrieve the containers for conveyance. Other details of the shelter should be left to consumers.

The storage containers should be watertight and large enough to accommodate the excreta that accumulate between collections. Containers large enough to contain the feces that accumulate during a three-month period for an average family of four are suggested, but containers should not be too large or too heavy for workers to handle safely when full. Containers must be made of a material that can withstand cold temperatures and the expansion of liquids during freezing. If full containers are to be stored, either on-site or off-site, then they should be sealed against insects, rats, and other vermin.

Workers must have access to the household sanitation facility to collect the containers and replace them with clean, empty containers. The collection agency and household members must collaborate to ensure efficient collection. Many types of collection vehicle are possible, from carts to small vehicles with trailers to large trucks.

Treatment often consists of composting, but other treatment methods are feasible. If the excreta are composted, sale of the composted product can help cover costs. However, people may be unwilling to use compost from human excreta, and some countries restrict its use. Therefore, an appropriate regulatory framework is critical, as is user education. Additional details on potential treatment methods, as well as reuse or disposal (which depends partly on the treatment method), is also discussed in more detail in the section on Common Elements in On-Site Sanitation Systems. The World Health Organization provides parameters for the safe reuse of wastewater and excreta, including composted or treated excreta (WHO 2006).

Operational/Maintenance Requirements

Household Level

Consumers must be trained to use urine-diverting toilets and to collaborate with the organization that collects the waste. When the feces container is full, the users must arrange collection of the container. The collection agency should collect the full containers promptly and replace them with clean containers. Users must ensure that workers and vehicles have access to the waste containers at the agreed-on times, and they must pay for the service regularly. One potential barrier to implementing this system is that some households may not be easily accessible by larger vehicles—or even smaller ones.

It would also be necessary to occasionally replace worn or broken containers.

Institutional Level

Users and the agency collecting the feces should collaborate to determine the collection schedule, and all parties must then adhere to it.

The agency must collect the excreta and convey it to another site for processing, often composting. This organization is responsible for maintaining and operating the fleet of vehicles that convey the waste, and it must also train, equip, and manage their workers to reduce the risk to their health, as well as to public health and the environment. The vehicles and containers used for collection require regular cleaning to control odors, limit corrosion, and prevent the spread of excreta and pathogens into the environment. At the same time, used cleaning water should not be allowed to spread into the environment.

Operation and maintenance of off-site treatment facilities depends on the type of treatment and must be managed by the agencies responsible. The organization treating the waste must protect the safety of its workers, the public, and the environment.

There should be enough households using the emptying system to pay for operating and maintaining conveyance and treatment systems. However, support from the government may be necessary.

The government must develop, implement, and enforce appropriate financial, institutional, and legislative arrangements to regulate and support the system. Even if a private sector organization collects and treats the waste, the government must provide oversight to protect public health and the environment.

Cold Climate Considerations

Reliable collection service depends on a usable street system with snow removal service and suitable vehicles equipped for operation in bad weather (four-wheel drive and tire chains, for example). Smaller motorized vehicles may have access where larger vehicles cannot go.

If waste is not collected during the winter, users must be provided with sufficient sealable storage containers to hold all the excreta generated during the cold season. If the storage containers are not well-sealed, odors after the waste thaws in the spring can be pervasive and obnoxious, and the waste may attract flies, rats, and other vectors.

It can be difficult to remove frozen excreta from containers, so containers should be designed to be emptied in the cold season. Or, if enough containers are available, the frozen excreta can be stored in them until the excreta thaws in the warmer weather. If the collected sludge is to be discharged to a sewer or treatment facility, frozen sludge must be thawed before discharge or treatment.

Water used to clean vehicles and containers will be contaminated and must be safely disposed of. This can be a major issue in very cold conditions because of the dangers from icy frozen runoff. It can also be an issue in warmer weather—if dirty cleaning water is not correctly disposed of, it can spread excreta and pathogens into the environment.

Construction/Installation Requirements

The containers that collect the excreta must be accessible for emptying. If the containers are placed in a hole or pit below ground level, the latrine superstructure must be built to give access to the container for collection. In all cases, the enclosure or container should prevent rats and other vectors and vermin from reaching the excreta.

If the superstructure is elevated above the containers, the structure underneath must be strong enough to support the superstructure, user interface, and users.

Construction requirements for treatment facilities depend on the method of treatment chosen.

Practical Experience in Cold Regions

The international NGO Action Contre le Faim (ACF) implemented a research project concerning container-based sanitation in Ulaanbaatar, Mongolia. The project installed about 370 UDDTs, collected the fecal sludge, and composted it. Researchers concluded that composting during the winter in Mongolia is possible only if heat is added to the process—for example, by composting in a heated building—which adds significantly to the treatment cost (ACF and USTB 2015). In the end, the project composted the sludge only in summer (Ryndin and Tuuguu 2015). However, experience since the end of the pilot project indicates that people there may not be willing to pay for emptying and collection of the waste, possibly because all costs were originally fully subsidized.[1]

Other haul systems, in which only the contents of on-site containers are collected, and not the containers themselves, have been used in Alaska and Canada for many years. However, the costs of construction and installation, or of operation and maintenance, or both, have generally been subsidized. In 2013, Alaska launched the Alaska Water and Sewer Challenge to find more sustainable systems and facilities for water supply and sanitation (The Department of Environmental Conservation, State of Alaska 2015).

Other Requirements

Container-based sanitation with UDDTs is a dry system that needs no water to function at the household level. Some water may be needed for composting and for cleaning containers and vehicles.

The space requirements at the household level are about the same (or slightly larger) than a simple pit latrine—that is, 4 to 5 square meters. Composting facilities may need to be quite large; land requirements for other treatment methods depend on the method selected.

At the household level, this system requires no added energy. However, energy is required to convey the waste, so depending on the type of treatment, energy may be needed to treat the waste.

Greywater Disposal

Container-based sanitation will not handle greywater.

Potential for Reuse

The potential for reuse of the excreta depends on the method of treatment. Container-based sanitation systems are often designed to produce humus for reuse as a soil conditioner or fertilizer.

Expected Life

A properly constructed and maintained container-based household sanitation facility should last for many years. However, it will be useful only when and if there is a system in place for collection and treatment of the waste.

Expected Costs

Capital Costs

In 2014 in Mongolia, UDDTs used with container-based sanitation cost about US$300 (Donati 2015).

However, this system involves other costs. The cost of a fleet of vehicles for waste emptying and collection can be considerable. The cost of building a treatment facility depends on the size, type of process, location, and support facility requirements. Containers will also need to be replaced occasionally.

Operation and Maintenance Costs

When the feces container is full, users pay a private service provider or government agency to collect the full container and replace it with a clean, empty one. Costs depend, in part, on the frequency of collection, which depends on the number and type of users as well as the size of the container.

The unit cost of each collection visit depends on the number of homes served, home access, road system, location, type of vehicles, distance between users and the treatment facility, and other variables. Costs will also increase if haulers must pay for disposal or treatment of the waste because they pass the cost on to the consumers. Consumers may not be willing or able to pay the full costs of collection and treatment. If the waste is treated by composting, sale of the composted material may help defray the costs. In some cases, authorities may need to consider subsidies. In ACF's pilot project, the estimated cost to empty a container was about US$7; this would cover costs only if all 370 users subscribed to the system of emptying (Donati 2015).

Operation and maintenance for waste treatment and disposal varies significantly depending on the type of treatment and/or disposal.

Other Advantages/Disadvantages

There is a risk that if disposal points are not near the areas where the tanks are emptied, haulers will empty the sludge into the environment, either on land or into surface water bodies.

Fees that users are willing to pay for this service are unlikely to cover the full costs of collection, conveyance, and treatment of the waste.

Variations

Bucket Toilet

Bucket toilets cannot be recommended unless they constitute an element of a carefully designed sanitation system. One option is for the bucket toilet to constitute an element of a container-based system, with a bucket that can be sealed when it is full, collected, and replaced with a clean, empty bucket. The full bucket is conveyed to a treatment facility where it is emptied and cleaned and the excreta treated for safe reuse or disposal. Alternatively, the bucket can be emptied into an intermediate container at the household level and the contents conveyed for treatment or disposal, or it can emptied into an on-site pit where the solids are stored indefinitely and liquids infiltrate into the soil.

Photo 3.10 Typical In-House Bucket Toilet
Source: © GV Jones & Associates, Inc. Used with the permission of GV Jones & Associates, Inc.

A bucket toilet consists of a plastic bucket, usually with a 20-liter capacity. The bucket can be set in a box with a seat or simply equipped with a seat, like the toilet in photo 3.10. This in-house option can be used during the cold season, for people with limited mobility, such as the elderly or the disabled, or for children. Bucket toilets can smell, but odors can be reduced by adding sawdust or ashes to the bucket after each use. In some Scandinavian countries, "ice" toilets are available for use in winter. These are bucket toilets that are kept cold in unheated spaces—the cold reduces the unpleasant odors. A small amount of electrical energy keeps the seat warm for user comfort.

Other components of this system can include a household or communal on-site pit, vault, or container for disposal or for temporary containment. Vehicles for hauling the waste and a treatment or disposal facility will also be needed if treatment is off-site.

An advantage of bucket toilets is that they can be used indoors by people with limited mobility. However, users must normally handle the full buckets to empty them, risking spillage and other accidents. Both users and collection workers can be exposed to pathogens in the excreta. They should be trained to follow safe practices and wear suitable protective clothing and equipment. Also, the contents are often not safely disposed of, so these toilets can pose a risk to public health and the environment.

Plastic bags can be used to line the bucket. When full, the bags are removed and conveyed to a treatment or disposal facility. Plastic bags make collection more hygienic—unless they break and spill waste. However, it is difficult to remove waste, especially frozen waste, from plastic bags for treatment. The bags need not be removed if the waste is to be deposited in a solid waste pit or landfill or if the bags are biodegradable (GV Jones & Associates, Inc. 2015b). However, experience has shown that sludge disposal at solid waste sites is complex and requires careful management to prevent health and environmental issues (UN-HABITAT 2009). Some solid waste disposal sites may not allow disposal of raw sewage, including in plastic bags. Full plastic bags should be protected from animals.

A small pilot project was implemented in Mongolia to test bucket toilets with on-site composting called Bio-Toilets. The waste was composted in open wooden bins located on household plots (Jenkins 2006). Although this project was never evaluated, the use of open bins near residential housing cannot be recommended because of the high risk of spreading excreta and pathogens into the environment.

Alaskans in small settlements have also used bucket toilets, but disposal of the excreta has often been unsatisfactory, posing a risk to public health and the environment. The Alaska Rural Water and Sanitation Working Group of the United States Arctic Research Commission, characterized bucket toilets as “truly the bottom of the scale with regards to sewage disposal” (2015).

Double-Vault EcoSan Latrine with On-Site Treatment

Above-ground double-vault latrines are not recommended for use in cold climates because the need for additional treatment for the sludge negates any advantage of the on-site treatment provided by these facilities. A double-vault latrine with on-site treatment consists of a facility with two adjacent water-tight vaults, built above ground level, in which the waste decomposes or dehydrates on-site.

The vaults are meant to be used one at a time, in sequence. The first vault is used until it is full, then it is closed. The second vault is used while the excreta in the first decomposes or dries. When the second vault is full, the first is emptied of the decomposed or dehydrated matter. The full vault is then closed and the first pit, now empty, is put back into use, as shown in figure 3.9. This cycle can continue for many years.

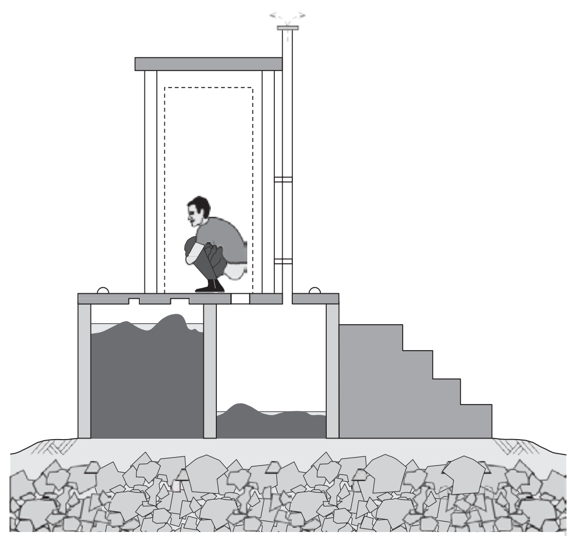

Figure 3.9 Double-Vault Latrine with On-Site Treatment

Source: Adapted from WEDC, Loughborough University.

The material emptied from the latrine cannot be considered safe to handle or to reuse directly after collection, especially in cold regions. It is highly likely to contain pathogens and pose a risk to human health and the environment. The need for conveyance and more treatment will increase operational costs significantly, so this option will have few, if any, advantages over container-based sanitation.

It can be difficult to move frozen excreta from a vault, so vaults should be emptied before the start of the cold season if there is not enough space to contain all the excreta generated during the winter.

In-House Composting Toilet

An in-house composting toilet is a manufactured unit, which can be recommended only if the spare parts and expertise to maintain it are readily available and if users are willing to monitor and operate it correctly. These toilets usually consist of a single unit that combines a toilet (user interface) with a composting chamber or chambers. Generally, in a cold climate, these toilets must be located inside the house or other heated enclosure. Ambient temperatures in the compost chamber should be kept above 10°C, which may require costly added heat.

There are many types and sizes of in-house composting toilet units and many manufacturers. Some units dry the waste by heating it and evaporating the liquid. Others compost all the excreta; still others divert the urine and compost only the feces. Normally, they produce an inoffensive humus that can be used as a soil conditioner or fertilizer. However, there may be little demand for the humus in cold regions, and local regulations may not allow its use in agriculture.

These units are complex, and users need training in their use, operation, and maintenance. Most models require a constant electrical power or propane gas supply. Acceptance has been limited, in part because of the need for frequent attention to operation and for periodic addition of bulking agents, which may not be readily available. Also, If the waste cools or freezes, aerobic microbiological processes can stop. Such disturbance of the biological treatment processes often results in obnoxious odors, and restarting the processes can require manual removal of the accumulated mass of waste, which is also obnoxious (Smith et al. 1996).

In many countries, units need to be imported; suppliers would also need to maintain a stock of spare parts and have the expertise to assist consumers with operation and maintenance. For that, suppliers would need to be assured of a sizable market for the units.

Low-Flush Toilet with Soakpit

Low-flush toilets, which offer a high level of service, are recommended only for users who are willing to pay the substantial additional costs and make the additional effort needed to install and operate these systems in cold regions.

Low-flush toilets use a small amount of water to convey excreta through sewer pipes, often to a soakpit or holding tank. Because of the risk of freezing, which would block and damage pipes and fixtures, they must be in a heated building.

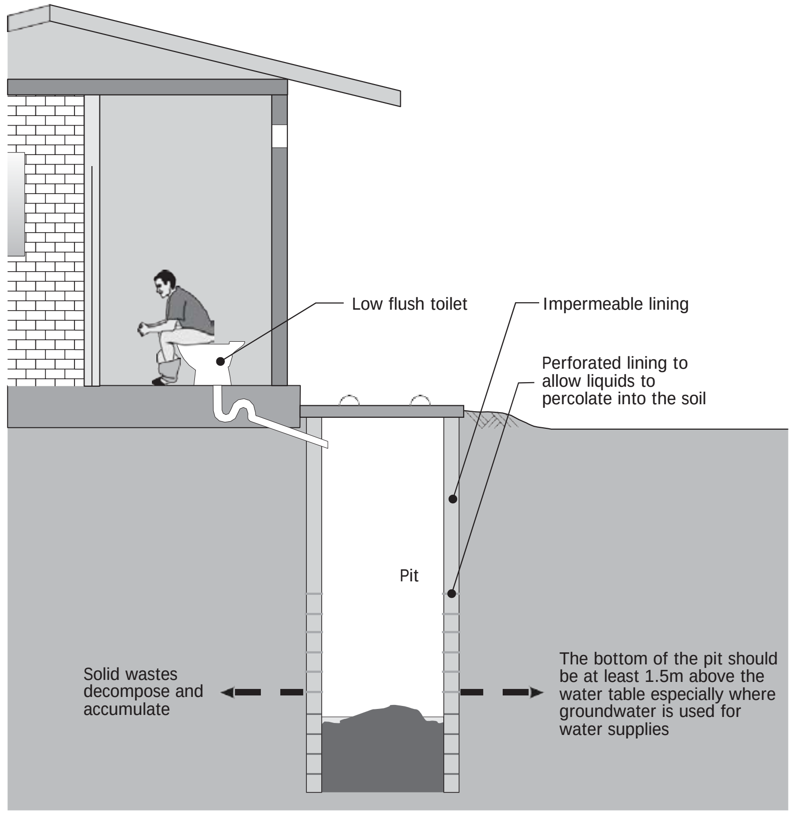

Figure 3.10 Pour Flush Toilet with Soakpit

Source: Adapted from WEDC, Loughborough University.

Low-flush toilets are available in a range of materials and models for use sitting or squatting; some do and some do not divert urine. Most have a water seal to control odors and flies. Many are designed to be flushed with very little water, often by users pouring water into the toilet fixture. These are called pour flush toilets and can use as little as 1 liter of water per flush. A pour flush toilet connected to a soakpit is shown in figure 3.10; a typical water seal is shown in figure 3.11. Cistern flush toilets, which store water for flushing in a small tank, are usually connected to a piped water supply. Even low-flush cistern flush toilets can use 6 liters or more per flush.

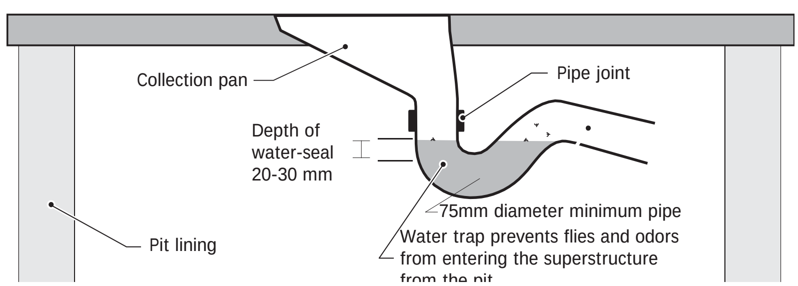

Figure 3.11 Typical Pour Flush Toilet Pan with Water Seal

Source: Adapted from WEDC, Loughborough University.

The soakpit, also known as a soakaway, cesspit, infiltration pit, or leach pit, is a covered pit connected to the toilet fixture by pipes. The pit must be lined to prevent collapse. The lower part of the pit lining should be porous to allow liquid to infiltrate into the ground during the warm season, when the soil is not frozen. Solids are retained in the pit and must be emptied periodically and conveyed off-site for treatment and reuse or disposal.

The technology is simple and inexpensive; built and used correctly, it produces no offensive odors and does not attract flies or mosquitoes. It has been widely adopted around the world; however, experience in cold regions appears to be quite limited.

Operational/Maintenance Requirements

Household Level

The low-flush volume and small size of the water seal means that only soft toilet tissue or water can be used as anal cleansing materials and flushed through the system. If other materials are used for anal cleansing, such as office paper or newspaper, they must be disposed of separately.

Solids will accumulate in pits, so they will need periodic emptying or replacement. Because pits must be lined, users will likely prefer to empty full pits instead of replacing them, which would be quite expensive. The pits must be accessible to vacuum trucks or other equipment for emptying.

Users need to haul enough water to operate low-flush latrines, which generally use 1.5 to 3 liters of water for each flush. Water for flushing does not have to be clean; greywater from bath or laundry use can be used, provided it does not contain grit or grease that can clog the soil pores and block infiltration of the wastewater into the ground. If the soil pores become blocked, the pit must be abandoned and replaced. This is especially important in places where people's diet includes large amounts of grease, oil, or fats.

Users must take care that the system does not freeze, in whole or in part, unless it is designed and built to allow for freezing.

Institutional Level

Emptying pits can be done by private sector suppliers or by government agencies. However, it is the responsibility of the government to ensure that there are options for the treatment and safe disposal of the sludge, as well as an appropriate regulatory and institutional framework.

Cold Climate Considerations

The development and testing of prototypes is needed, but pour flush toilets should be able to function successfully in cold regions provided precautions are taken, as follows:

- The toilet fixture and trap must be in a heated space to prevent the water in them from freezing.
- The sewer pipe that connects the toilet fixture to the exterior pit should be short and insulated or heated to prevent ice or frozen waste from building up in the pipe and blocking it.
- The slope of the sewer line from the house to the tank needs to be designed so that a lower volume of liquid will carry solids through the pipe in one flush, without plugging it or leaving waste in the pipe to be frozen.
- Unless the waste in the soakpit can be prevented from freezing, the pit should have enough empty space at the start of the cold season to contain all the wastewater that will be generated during the winter. It may be possible to dig the pit below the depth of freezing; however, the soil around the pit can freeze to a greater depth than undisturbed soil because the pit can allow cold air to circulate and cool the contents of the pit and the soil around it.
- The water seal in a toilet fixture can sometimes be winterized by pouring a small amount of nontoxic antifreeze into the water seal. The antifreeze will not freeze as readily as water if the house is allowed to cool (for example, when the house is unoccupied for some time).
- A mechanism, such as a heat cable, to thaw the contents of the pipes in case of accidental freezing is needed.

Construction/Installation Requirements

The pour flush toilet fixture (pedestal toilet or squatting pan) is usually located within the resident's house or other permanent structure.

Pour flush toilets generally use less water than a conventional cistern flush toilet, but they require a toilet pan or pedestal seat specifically designed for low-volume flushing.

The soakpit contains the solid portion of the wastewater and allows the liquid portion to soak into the surrounding ground. The soakpit may be placed directly under the toilet fixture or offset and connected to the toilet fixture by a pipe. It can be wholly or partially under a building, provided there is access to the pit for emptying.

Especially in cold regions, the pipe between the toilet fixture and the pit should be as short as possible: 1 to 2 meters is best. The pipe should also have a steep slope to ensure that the waste moves rapidly through it. If the pipe is longer or laid at a shallow gradient, more water will be required for flushing. There will also be a greater risk that water or waste will remain in the pipe and freeze.

The pits are generally 1.5 to 4 meters deep and have a porous lining to support the pit cover and prevent pit collapse. The bottom of the pit should be at least 2 meters above the water table if the groundwater is to be used for human consumption. In any case, the pits should be located a safe distance (ideally more than 30 meters) from any source used for human consumption to minimize contamination. If possible, the groundwater should flow from the leach field or pit away from the source. If the location has rock or groundwater close to the surface, the pour flush latrines can be raised on a mound (see the previous section on raised latrines).

The technology works best in porous soils that will readily absorb the liquid part of the wastewater. Soils must be tested to ensure that they are porous enough to allow adequate infiltration of liquid waste. Soakpits should not be built in high-traffic areas where the soil above and around it can be compacted.

Practical Experience in Cold Regions

Pour flush toilets have not had extensive use in Alaska or other cold regions because of problems with the pipelines and outside vault freezing. Toilet fixtures that are flushed with small amounts of water to insulated vaults that are emptied regularly have been used in Canada. However, outside vaults must be well-insulated and/or have heat added. The contents should not freeze because frozen waste can damage the vaults and cannot be removed until it thaws (GV Jones & Associates, Inc. 2015b).

A small number of users in Ulaanbaatar, Mongolia, have constructed household-level water supply and sanitation systems using trucked water, with flush toilet fixtures and tanks that receive the wastewater. Greywater and blackwater alike are conveyed via pipes to tanks that are close to the house. None of the owners report having emptied the tanks, though some had been in use for several years. Most likely, the tanks are not watertight, and liquid infiltrates into the ground during the warm season.

Other Requirements

A pour flush toilet requires an estimated total of 3 to 5 liters per capita (person) per day (lcd) of water per user for flushing, and a low-flush latrine requires 20 to 40 lcd (The Sphere Project 2011).

The toilet requires a space in the house or other heated building; most people will prefer a dedicated space for privacy for users.

Depending on its design, a system using a pour flush toilet should not require added energy unless pipes are frozen accidentally and need to be thawed.

Greywater Disposal

Systems of this type may be able to handle some greywater. The amount will depend on the dimensions of the pit and the porosity of the soil. However, in cold regions, the soakpit will need to be large enough to hold both greywater and blackwater generated during the winter months when the ground is frozen.

Potential for Reuse

Sludge emptied from the pit would require further treatment before it can be reused.

Expected Life

A well-designed, well-built, and well-maintained pour flush system should last for many years. However, considerable effort may be required to prevent a pour flush system in a cold region from freezing.

Expected Costs

Capital Costs

The cost of indoor plumbing is moderate to high, depending on user preferences; however, the cost of lining a pit or insulating a vault is also often high.

Operation and Maintenance Costs

Users must be willing to pay for the water required for flushing the toilets. They must also be willing to pay to periodically empty the pit of accumulated solids.

Variations

Low-Flush Toilet with Watertight Vault/Holding Tank

Low-flush toilets with watertight vaults, also called holding tanks, are not recommended unless there is an agency willing and able to empty them frequently and to convey and treat the waste for safe reuse or disposal.

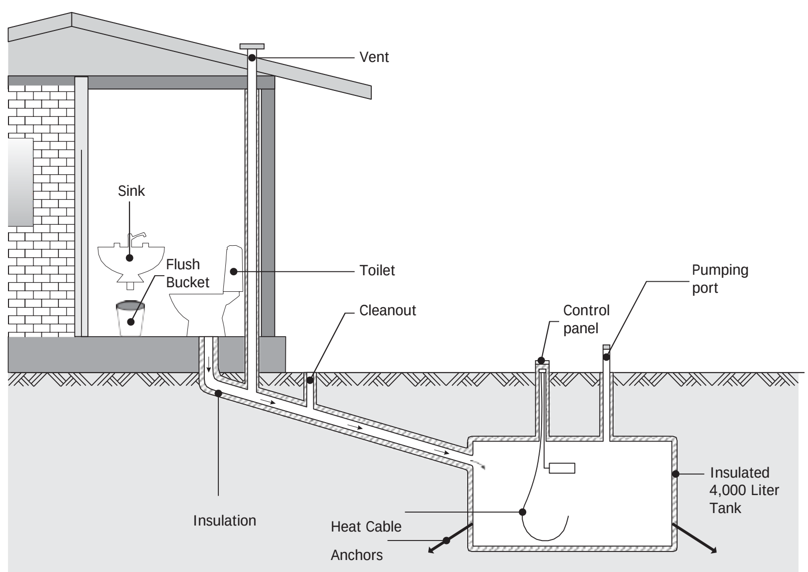

Figure 3.12 Offset Buried Holding Tank

Source: GV Jones & Associates, Inc. Used with the permission of GV Jones & Associates, Inc.

Although similar to the pour flush latrine described previously, this toilet is connected to a watertight vault rather than a soakpit. The vault can be above ground or buried. A toilet flushing to an insulated buried holding tank is shown in figure 3.12. The vaults can serve single households or small groups of households. However, conveying waste through pipes to communal holding tanks is feasible only where higher volumes of wastewater are generated to carry the solids through the longer pipes.

As in other types of flush toilets, if the toilet fixture has a water seal or a cistern, then it must be in a heated enclosure, such as a room in a house, lest the water freeze and damage the fixture. Vaults and pipes must also be protected from freezing by some combination of insulation, added heat, or burial below the depth of soil freezing. Mechanisms for emergency thawing and access points for maintenance are needed (GV Jones & Associates, Inc. 2015b). Also, users must be able to afford both the emptying and the heat to keep the vaults from freezing.

When the vault is full, it is emptied, usually by a mechanized device such as a vacuum truck. Its contents (blackwater from flush toilets and greywater from other household uses) are conveyed to a wastewater treatment facility or designated disposal site. The vaults must be accessible for vehicles and can be equipped with quick connection couplings to minimize spillage during emptying.

These systems are expensive to construct and to operate at the household and communal levels. A fleet of appropriate vehicles must be purchased, maintained, and fueled. In addition, facilities for treatment and/or safe disposal of the emptied excreta will be required. This type of system has been used in Canada and Alaska but has generally been heavily subsidized.

Aqua Privy

Aqua privies are not recommended for use in cold regions unless testing and research determine that they can be designed for use in cold environments.

Aqua privies are equipped with watertight vaults filled with wastewater located directly under the toilet. Excreta drops into the vault through a pipe that extends into the water, forming a water seal. The solids settle in the tank and must be emptied periodically and taken to a facility for further treatment and disposal. The liquid waste, or effluent, flows to a secondary treatment mechanism, such as a soakpit, infiltration pit, leach pit, leach field (also called an infiltration field or gallery), or sewage lagoon, or to a sewer (WEDC 2014). The vault can receive some greywater. An aqua privy with soakpit is shown in figure 3.13.

In cold regions, care must be taken that the tank and the leach pit or infiltration field do not freeze. Also, because the vault is under the home, it must usually be built at the same time as the home.

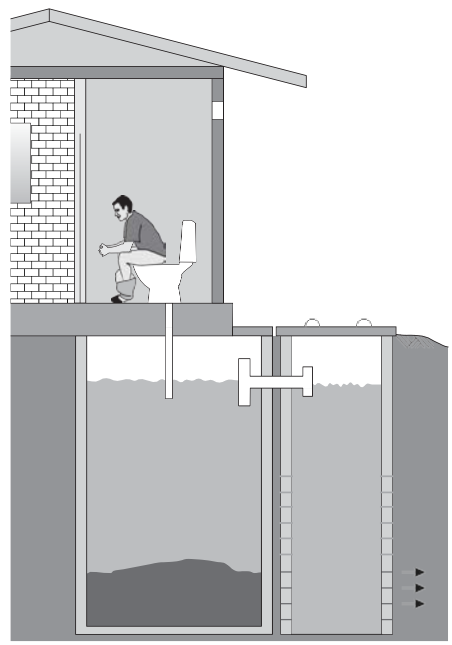

Figure 3.13 Aqua Privy with Soakpit
Source: Adapted from WEDC, Loughborough University.

Double Pit Pour Flush Toilet

Double pit pour flush latrines are not recommended because they risk freezing and have no clear advantages in cold regions. This type of low-flush latrine is constructed with two shallow pits. The pits are used sequentially, one at a time. When the first pit is full, the second is brought into use. In theory, the contents of the first pit will decompose and the pathogens will be inactivated while the second pit is in use. The first pit is then emptied and the pit reused while the contents of the second pit decompose. This cycle can be repeated many times.

However, because the pits are usually shallower than for a pour flush toilet with one pit and the connecting pipework is longer, protecting them against freezing is challenging. Moreover, because the pipes are longer, double pits generally require higher volumes of flush water than single pour flush latrines, so the pits would need to be larger to accommodate a greater volume of wastewater generated during the cold season.

This technology is unlikely to be cost-effective in cold climates because the sludge normally needs additional treatment to sanitize it. The additional conveyance and treatment will involve additional costs and negate the usual advantages of the double pit arrangement. Figure 3.14 shows a typical double pit pour flush toilet facility.

Figure 3.14 Double Pit Pour Flush Sanitation System

Source: © Eawag. Used with the permission of Eawag. Further permission required for reuse.

Flush Toilet with Septic System

In moderately cold climates—for example, where the soil freezes to a depth of 1 meter or less—flush toilets with septic tanks that empty to leach fields or leach pits may be an option. However, depending on the depth of freezing, preventing freezing of septic systems can be prohibitively expensive. The contents of the septic tank may freeze unless heat is added, and freezing can damage the tank and block the system.

Leach fields that are not buried below the depth of freezing are also likely to freeze. Liquid cannot seep into frozen soil, causing effluent to back up into the tank, with disastrous consequences. Liquid in leach pits will not be able to infiltrate into frozen soil. Moreover, the pit can act as a conduit for the cold, and soil around the pit will then freeze to a greater depth than the soil farther from the pit.

Sewers

Sewers can be recommended only in urban areas with adequate water supplies to ensure their functioning. In cold regions, designers must carefully consider the thermal balance of the sewage so that it does not lose so much heat during conveyance that it freezes in the pipes. This is especially true for long pipelines with low flows, where heat loss can be significant. Frozen sewage will block the pipes and can be difficult to thaw. Burying pipes below the frost depth—to prevent freezing—can be prohibitively expensive, not to mention difficult in places where bedrock or groundwater is close to the surface. Storing the soil from deep excavations can take a great deal of space, and deep excavations may need to be shored. Moreover, treating chilled sewage may be less efficient than treating warm sewage because most treatments are biological processes that are temperature-dependent.

Conventional sewer networks may be the most cost-effective option for sewerage systems. Alternative sewer systems, such as condominial sewers, pressure sewers, vacuum sewers, small diameter sewers, and settled sewage systems are particularly vulnerable to freezing. They are often buried at shallow depths, have smaller diameters and shallower gradients, and operate with smaller volumes of wastewater, all of which make them prone to freezing. Thus, such systems cannot generally be recommended.

Greywater Disposal

In low-income urban and peri-urban communities without sewers, the disposal of greywater—that is, used water from domestic uses such as bathing, cooking, laundry, or cleaning that does not contain excreta—can be a problem. When water consumption is low (10 to 15 lcd), greywater can usually be disposed of in on-site excreta disposal systems such as pit latrines, or it can be thrown onto wasteland to infiltrate into the soil. Even in cold climates, disposal of small amounts of greywater is rarely a serious problem as long as it is not thrown on the ground surface, where it can create an icy hazard. During winter, greywater can be placed in the latrine pit, where it will freeze and accumulate with fecal matter. In this case, the pit must be large enough to accommodate the greywater as well as the excreta generated during the cold season. In the warm season, the liquid will infiltrate into the surrounding soils.

The problem arises when water consumption increases. The volume of greywater increases, and these methods of disposal are no longer adequate. The infiltration capacity of pit latrines, or of the ground near the household, will probably not be sufficient to absorb the increased quantity of liquid. In hot and temperate climates, a frequent solution is to construct roadside drains that collect the greywater and carry it to a nearby watercourse. This is not an option in cold climates because in winter, the greywater quickly freezes, turning the streets into sheets of ice and creating a major health and safety issue. The installation of a water-borne sewerage system would solve the problem, but that becomes viable (assuming the funds are available and other conditions are favorable) only when water consumption reaches about 60 to 100 lcd. So what to do when the water consumption is between 15 and 60 lcd?

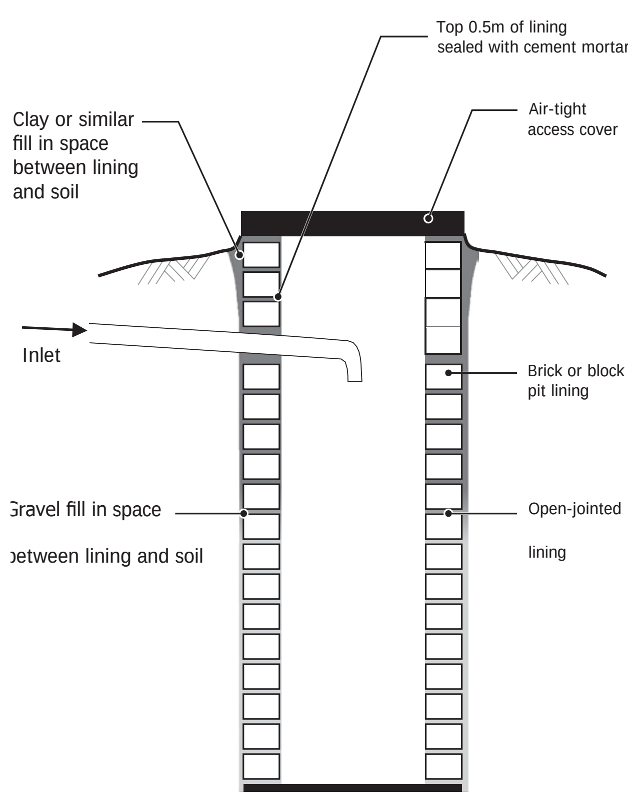

Figure 3.15 Typical Lined Soakpit
Source: Adapted from WEDC, Loughborough University

Unfortunately, the solutions are neither easy nor cheap. Depending on local circumstances, such as the depth of soil freezing and other soil conditions, the options are either subsurface infiltration or storage for off-site disposal. If either of these becomes necessary, consideration should be given to combining greywater disposal with improved excreta disposal facilities; the additional cost of combining the two functions is often marginal.

Reuse

Water that has been used for bathing, washing dishes, laundry, or other household purposes can often be reused. For example, water from washing clothes or dishes can be used to clean the house, water plants, flush a toilet, wash a car, and so forth. Reusing water also reduces the amount of water that users must purchase or haul to the home.

Subsurface Infiltration

If the soil does not freeze to more than 1 or 2 meters, a soakpit or infiltration trench—like that used for septic tanks that extends below the depth of soil freezing—can be installed. Of the two, seepage pits are probably best because the greywater can be discharged directly into them. Infiltration trenches require a preliminary settlement tank to remove gross solids and fats to prevent the trenches from blocking. Even for seepage pits, however, fats, grease, and oil should not be put into the pit because they will block the pores in the soil and reduce infiltration.

If the soil freezes to a great depth in winter, it may be possible to construct a soakpit large enough to hold all the greywater produced during the cold season. When the soil and the greywater thaw, then the greywater can infiltrate into the soil. This will work only in porous soils, however, so that all the greywater generated during the year will infiltrate into the soil during the time that the soil is thawed. Figures 3.15 to 3.16 show examples of soakpit designs.

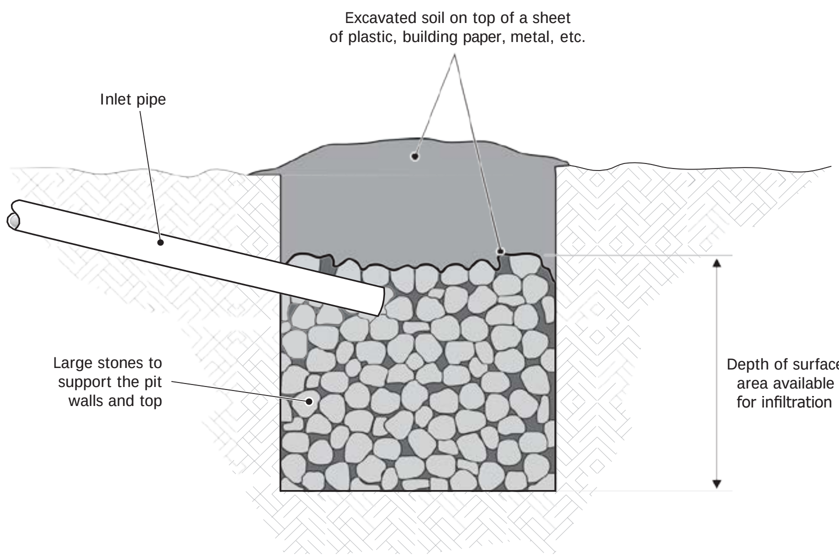

Figure 3.16 Typical Unlined Soakpit

Source: Adapted from WEDC, Loughborough University.

Storage for Off-Site Disposal

Where the soil is not sufficiently porous or where there is insufficient space for an on-site disposal system, an off-site system must be considered. An insulated below-ground holding tank—like that used in vault latrines or household holding tank systems—will be required. These can then be periodically emptied by vacuum tanker and the wastewater taken away for treatment and disposal. However, the tank's contents must be prevented from freezing because they will expand on freezing and damage the tank. Moreover, the contents cannot be emptied when frozen. Frozen greywater can also block and damage pipes.

Note

1. Robert A. Reed, personal communication, March 2017.

Appendix : Practical Experience in Cold Regions

Experience in Alaska and Canada

Bucket Toilets

During initial attempts to improve sanitation in villages in Alaska and Canada, many people used bucket toilets inside their houses. The buckets, when full, were emptied into pit latrines built near each house, which soon filled. Some families excavated new latrines, but other families abandoned the full latrines and reverted to dumping the excreta onto the ground.

Photo A.1 Underground Communal Wastewater Tank, Alaska

Source: © GV Jones & Associates, Inc. Used with the permission of GV Jones & Associates, Inc.

An attempt was made to improve the situation by constructing large communal underground structures or bunkers—away from the house—where homeowners could dump the contents of the buckets. The bunkers filled within a few years. Users then deposited waste on top of the bunkers, as shown in photo A.1, which posed a serious risk to public health and the environment.

Photo A.2 Emptying a Bucket Toilet into an Intermediate Storage Container, Alaska

Source: © GV Jones & Associates, Inc. Used with the permission of GV Jones & Associates, Inc.

To improve the situation, a haul system was provided that used communal mobile collection tanks. Users discharged excreta from bucket toilets into the tanks, as seen in photo A.2. The waste froze into large solid “ice waste bricks” in winter, which could be removed easily from the tank. Once removed, the frozen waste brick could be hauled to a remote site for disposal. However, the tanks were often overfilled and excreta spread into the environment during summer months. During the winter months, the high-density polyethylene (HDPE) plastic tanks were sometimes broken when people pounded on them to loosen the frozen waste for removal.

Vehicle Haul Systems

Another newer haul system uses 750- to 1,000-liter closed holding tanks attached to the house, as shown in photo A.3. Because the houses were heated, the waste does not freeze. Small vehicles with trailer-mounted tanks pump out the waste and haul it to ponds that provide biological treatment (see photo A.4). Improved roads allow year-round access to the homes. Indoor plumbing fixtures such as toilets, sinks, or showers were designed to use small amounts of water. A modification of this system uses vacuum systems for wastewater collection with insulated above-ground storage tanks. This system can use smaller haul vehicles.

Photo A.3 Closed Vehicle Haul System

Source: © GV Jones & Associates, Inc. Used with the permission of GV Jones & Associates, Inc.

The advantages of a closed-tank pump-out system include minimal spillage and, consequently, reduced risk of disease transmission within the community; a lower capital cost than conventional sewerage; and quick, easy setup.

However, this type of system may be too expensive for users to operate and maintain if there is no subsidy. Installation costs were covered by government grants, and operating costs are also subsidized. This system is currently being used in approximately 20 communities in Alaska—that is, approximately 1,000 homes.

Photo A.4 Emptying a Small Closed Haul Vehicle

Source: © GV Jones & Associates, Inc. Used with the permission of GV Jones & Associates, Inc.

Sewerage

Many communities in Alaska have replaced the haul systems with piped water and sewer networks, which provide a better service to the consumer. Nonetheless, the piped systems generally require subsidies to construct and to operate. Sewer systems that can operate in very cold conditions are generally more expensive and complex to construct and to operate than sewer systems in more moderate climates.

Composting

Like sewerage, successful use of ecological sanitation at scale, including composting, requires good management and appropriate regulatory, institutional, and financial arrangements, often including subsidies and technical support. Successful examples of large-scale sludge composting systems in cold climates include Fairbanks, Alaska, and Edmonton, Canada, which co-compost sludge from wastewater treatment facilities (Alaska Rural Water and Sanitation Working Group 2015).

Other facilities that compost human excreta in cold regions, including composting toilets, and facilities in rural communities, have had limited success for a number of reasons, including the following (GV Jones & Associates, Inc. 2015d):

- High costs of operation, including fuel, electrical power, equipment, and storage buildings, especially for smaller facilities without economies of scale
- The need for a consistent source of carbon and bulking agents and their cost
- The need for large land areas and the objections of potential neighbors
- The need for monitoring and corrective measures by trained employees, supported by management
- Disruption of biological processes because of cold temperatures, which is more likely with smaller volumes of excreta, as found in individual latrines
- Disruption of processes due to inadequate or excess moisture, inadequate oxygen, or poor carbon-to-nitrogen ratios
- Poor-quality end product (compost) that does not meet regulatory standards
- No demand for the compost
- Bad smells if not operated properly

Alaska Water and Sewer Challenge

In 2013, the Alaska Department of Environmental Conservation launched the Alaska Water and Sewer Challenge to address the water and sanitation needs of rural Alaskan households. Its goal is to significantly reduce the capital and operating costs of in-home piped water supplies and improved sanitation. Criteria include constructability, health benefits, affordability, and other operational considerations. Funding for conventional communitywide piped and truck haul systems has declined severely while costs have risen sharply. Capital and operating costs of traditional approaches to water supply and sanitation have become unsustainable (The Department of Environmental Conservation, State of Alaska 2015).

The need for the Alaska Water and Sewer Challenge demonstrates that even a relatively wealthy state, such as Alaska, is considering replacing expensive and complex vehicle haul or piped sewerage systems with decentralized water and wastewater treatment, including recycling and water use minimization for individual homes and housing clusters. However, the solutions selected for development in Alaska are likely to require considerable institutional and logistical support, reliable electrical power, specialized spare parts, and expert maintenance (The Department of Environmental Conservation, Division of Water, State of Alaska 2015). There will still be a need for solutions suited to developing nations.

The Erdos Project, China

The Erdos Project was a large-scale, multiyear project constructed in Erdos City, Inner Mongolia (China). The project was intended to showcase the use of ecological sanitation (EcoSan) toilets in an urban setting. It focused on separating the waste streams (feces, urine, greywater, and solid waste) for recycling and reuse (Rosemarin et al. 2012).

The project was constructed to serve 3,000 residents in 832 apartments in 43 four- or five-story buildings. The total investment for the project was about US$ 17 million, of which about $US1.4 million was for the dry toilets, greywater treatment, and composting systems. Households paid 70 percent of the investment, with 25 percent from the regional government and 5 percent from the international development agencies. The project was completed in 2009, and the residents started lobbying to change to flush toilets immediately.

Although EcoSan systems have been successful in cold climates, in Erdos City, consumer complaints about the EcoSan system resulted in it being replaced by a conventional sanitation system. The failure of the system demonstrates the importance of involving consumers in the planning and design of sanitation services, socioeconomic research and testing to ensure that the selected technology suits people's aspirations and willingness to pay, as well as physical conditions. Poor-quality construction also reportedly played a part in users' rejection of the system. Financial viability was yet another factor—an economic analysis of the EcoSan sanitation system showed that it was more expensive to build and maintain than a conventional sanitary sewer system. The system would have provided several benefits from recycling, use of solid waste products, and wastewater reuse, along with other external benefits, such as improved health and an improved environment. However, the agricultural areas were 30 kilometers away, which might have been too far to profitably transport humus for reuse (Rosemarin et al. 2012).

Sanitation in Peri-Urban Areas of Ulaanbaatar, Mongolia

Ulaanbaatar, Mongolia, is the coldest national capital in the world. In winter, the soil freezes to depths averaging 3 to 4 meters, and there is some discontinuous permafrost. Only about 40 percent of the population is served by piped water and sewer networks to their homes. More than 750,00 peri-urban residents depend on basic, generally unhygienic pit latrines.

Photo A.5 Container-Based System with Urine-Diverting Dry Toilet in Ulaanbaatar, Mongolia

Source: World Bank.

Container-Based Sanitation

The international nongovernmental organization (NGO) Action Contre le Faim (ACF) implemented a project to research the potential use of container-based sanitation to improve sanitation in Ulaanbaatar. From 2009 to 2015, the project constructed urine-diverting dry toilets (UDDTs) with off-site composting for 370 households. In most models, the user interface was raised and the container that received the feces was placed on a ground-level slab below it, as seen in photo A.5. One model featured a movable ground-level superstructure with the receptacles for the feces placed in a pit below it. However, it was difficult to lift the full containers from the pit for collection. For all models, urine was diverted to a soakpit and allowed to seep into the ground. Sawdust was added to the container after defecation, and the receptacles full of feces and sawdust were taken to a central composting facility and treated there.

The project found that container-based sanitation with off-site composting in Ulaanbaatar was technically feasible. ACF concluded that the fecal sludge from the entire year could be successfully composted during the warm season. During the cold season, the collected excreta was simply stored at the household in the container and then collected in the spring.

However, once the project ended, people proved unwilling to pay for the collection of excreta. The project, established for research purposes, had fully subsidized all costs during the project. A different approach may have been more sustainable. Also, regulations prevented the sale of the composted material to offset costs. Even if its sale been allowed, there may not have been much demand for the compost because not many people plant gardens.

Wet Sanitation

A socioeconomic survey by the World Bank (Roger 2015) found that about 3 percent of households living in detached houses in the Ger areas of Ulaanbaatar had flush toilets, even though they were not connected to a sewer or a piped water supply. These households had plumbing fixtures that included flush toilets and piped water for the kitchen, bathing, and laundry. Water was purchased and brought to the house by vehicle and stored in a tank. Both greywater and blackwater were conveyed through household-level sewer pipes to a storage tank or soakpit, as shown in figure A.1. The collected wastewater was emptied by vacuum tanker and discharged to the city's sewer network. All the households visited also had a pit latrine outside the house for guests, as many people preferred to defecate outside rather than in an indoor toilet.

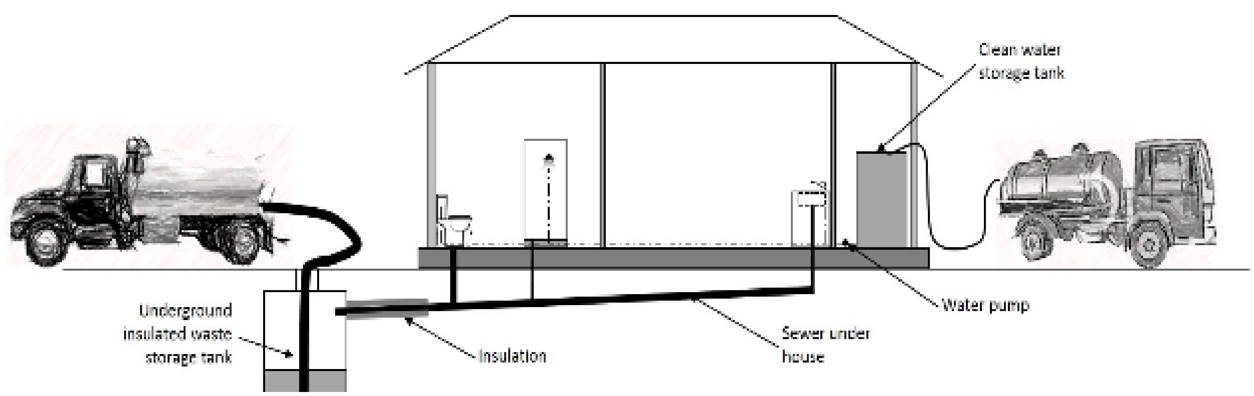

Figure A.0.1 Typical Household-Level Sewerage Network
Source: Personal communication, Reed 2016

Sanitation in Greenland

Greenland has a cold climate with long winters and a very scattered population with isolated communities, mainly along the coast. In towns, residents have either traditional flush toilets or bucket toilets, depending on the community's water supply. In scattered communities, the use of bucket toilets is almost universal. Bucket toilets are sometimes emptied by municipalities and private companies but also by individuals. Some of the excreta are disposed of in sewers, but some is just thrown onto open land or into the sea. Flush toilets are connected either to a sewerage system or to a holding tank. Holding tanks are pumped out by municipalities or private companies with the waste being discharged to sewers. Virtually all sewage (residential and industrial) is discharged, untreated, to the sea. Greywater is often discharged onto the ground surface.

Bucket toilets have been considered a problem for many years because of pollution and the possibilities of health risks, and a few pilot projects were implemented to test alternatives. Two designs of improved facility—with urine diversion pedestal seats—were tested. The excreta were stored in a porous container below the pedestal. The urine soaked into the ground, and the containers full of feces were removed and emptied into the sea. The new toilets were considered an improvement over the previous bucket latrines but were ultimately unsuccessful because of problems with odor and sludge. A low-flush (1-liter) toilet connected to a holding tank was also tested, but poor installation resulted in poor operation (Gunnarsdottir 2012).

Glossary

Blackwater	Wastewater from a toilet facility, which contains feces and/or urine.
Cold regions	For the purposes of this report, places with mean monthly temperatures below 1°C or for at least one month per year. These are regions where the design of water and sanitation facilities must consider the thermal implications of cold temperatures.
Compost	An earthlike humus produced by composting, which can be used as a soil conditioner or fertilizer.
Composting	A biological process in which microorganisms, including bacteria and fungi, aerobically decompose biodegradable organic matter to produce an earthlike material, often called humus (Tilley et al. 2014).
Composting latrine	A dry toilet facility in which organic material such as vegetable waste, straw, grass, sawdust, or ash is added to the excreta. Special conditions are then maintained so that the material decomposes (composts) into an inoffensive earthlike material called compost or humus. The latrine may or may not have a urine separation device. This toilet is one version of an EcoSan (ecological sanitation) toilet.
Dehydrating latrine	Treats excreta by dehydration (drying) rather than decomposition (composting). Urine is normally diverted or separated from feces. Drying toilets are a type of EcoSan (ecological sanitation) latrine. The dried excreta can be used as a soil conditioner only if it is sanitized because dehydrating toilets are not likely to destroy or inactivate all pathogens. The urine can also be used as a fertilizer, either separately or combined with feces, because it contains high levels of nutrients.
Ecological sanitation	Also known as EcoSan. An approach to wastewater management that aims to safely recycle the nutrients, water, and/or energy contained in excreta and wastewater, thus minimizing the use of nonrenewable resources for energy, nutrients, and water.
Effluent	The liquid portion of wastewater that remains after solids have settled out.
Excreta	Human feces, urine, or a mixture of both.
Fecal-oral disease	Disease caused by pathogens in feces that enter the host through the mouth via food, water, hands, and other sources that have been contaminated by feces.
Fecal sludge	Waste material that has been emptied from on-site sanitation facilities such as latrines or septic tanks. Characteristics vary. For example, sludge can be raw—that is, untreated—or partially digested. It can be a low-viscosity slurry or fairly solid (Tilley et al. 2014).
Geohydrology	A science that deals with groundwater and its physical and chemical interactions with the physical environment.

Greywater	Domestic liquid waste without any excreta—that is, water from washing, bathing, laundry, or other household uses.
Improved sanitation facility	Facility that protects and promotes human health by providing a clean environment and breaking the cycle of disease. It promotes sustainability by being economically viable, socially acceptable, and technically and institutionally appropriate.
Latrine	A broad term that covers a range of basic sanitation facilities. This report uses the following definition as related to cold regions: An unheated outside structure where people defecate. It usually has a waste pit, vault, or storage container under the structure or offset from it. It is equipped with a user interface (squatting slab or seat pedestal) for the user's convenience. The superstructure (sometimes called a cabin) is a shelter made of wood, plastic, metal, concrete, or other materials. The latrine can store waste permanently, or the waste can be removed periodically for later treatment by a variety of processes.
Leach field/septic drain field/infiltration gallery	A series of subsurface trenches or chambers designed to facilitate the infiltration of effluent into the soil. Infiltration removes most contaminants and impurities, including pathogens, depending on soil conditions.
Leach pit/soakaway/soakpit/seepage pit/infiltration pit	A hole in the ground used for the disposal of liquids. The walls of the pit are porous so that excess liquid can soak away into the surrounding ground. In some countries, the term cesspit is also used; in other countries, a cesspit is a watertight in-ground vault.
Permafrost	A layer of soil or rock beneath the surface of the ground in which the temperature is continuously below 0°C for two or more years.
Pit	For the purposes of this report, a hole in the ground used for the disposal of human excreta and/or sullage. The walls of the pit are porous so that excess liquid can soak away into the surrounding ground. The walls can be lined, unlined, or partially lined with a variety of materials. If lined, the lining should also be porous except for the uppermost 0.5 meter.
Sanitation	For the purposes of this report, the management of human excreta. Most of this review concerns the safe management of human excreta.
Sanitization	The elimination or inactivation of pathogens in the sludge.
Septage	A type of fecal sludge, usually settled solids, removed from septic tanks or holding tanks and normally of low viscosity.
Sewage sludge	Sludge that originates from a sewer-based wastewater collection and conveyance network and a centralized or semicentralized wastewater treatment plant.

Sludge	Waste consisting of a mixture of solids and liquids, mostly excreta and water, from an on-site sanitation facility, such as a latrine or septic tank, or from off-site facilities, such as wastewater treatment plants. Sludge may also contain grit, fats, oil, grease, metals, trash, and chemicals and can be untreated or partially treated. It can be a slurry or semi-solid, and it can contain greywater.
Stabilization	The degradation of the sludge or liquid waste through biologic processes into more stable, less degradable organics, thereby reducing oxygen demand and odors and making the sludge easier to handle.
Sullage	See *greywater*.
Sustainable sanitation	A system that is economically viable, socially acceptable, durable, and technically and institutionally appropriate. It should function properly throughout its design life, protecting the environment and natural resources.
Toilet	The receptacle into which the user defecates.
User interface	The toilet, pedestal, pan, or urinal by which the user accesses the sanitation system and deposits excreta. It is the part of the system with which the user comes into contact with the system. It can also include the slab that supports the user and the toilet.
Vault	A watertight container (tank), above or below ground, used for the collection of human excreta and/or sullage. The vault is periodically emptied and the waste taken away for treatment and disposal.
VIP latrine	Ventilated improved pit latrine. A form of pit latrine that includes a ventilation pipe to reduce odors in the toilet cubicle and requires the superstructure to be kept dark to minimize problems with flies.
Wastewater	Waste that includes both toilet waste (blackwater) and domestic liquid waste (greywater).
Wastewater sludge	See *sewage sludge*.

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