Situation analysis and recommendations for an improved wastewater disposal system at Saint Francis Hospital in Zambia

by

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Certificate of Authorship

I certify that:

(i) I am responsible for the work submitted in this project report, and that the original work is my own.

(ii) I have not submitted this work to any other institution for the award of a degree.

(iii) All field work has been carried out by me with no outside assistance except as noted below:

- *The water quality measurements were carried out in April 2012 by Mr Mtonga from the SFH microbiology laboratory, supervised by Paul Splint.*
- *The various other measurements, site surveys and observations were all carried out by me, sometimes with partial assistance from Paul Splint and Jim Oliver.*
- *All interviews were led by me, while Jim Oliver and Paul Splint sometimes posed additional questions. The answers to those questions, in some cases, proved to be useful for this study as well.*

(iv) All information (including diagrams and tables) or other information which is copied from, or based on, the work of others has its source clearly acknowledged in the text at the place where it appears.

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Abbreviations:

CHAZ – Churches Health Association of Zambia

DTF – Devolution Trust Fund

ET – Evapotranspiration

EWSC – Eastern Water and Sewerage Company

FS – Faecal sludges

FSPs – Faecal Sludge Ponds

MOH – Ministry of Health

MoU – Memorandum of Understanding

NTS – Nursing Training School

O&M – Operation and Maintenance

PL – Pit Latrines

SFH – Saint Francis Hospital

ST – Septic Tank

WEDC – Water, Engineering and Development Centre

WHO – World Health Organization

WSPs – Waste Stabilization Ponds

ZMK – Zambian Kwacha (4,822 ZMK = 1 USD on 07/08/2012)

Scientific Notations:

BOD_5 – Biological Oxygen Demand over a 5-day period

°C – Degree centigrade

CFU – Colony Forming Unit

COD – Chemical Oxygen Demand

mg/l – Milligram per litre

pH – Acidity level or Alkalinity level

TSS – Total Suspended Solids

1 Introduction

1.1 Saint Francis Hospital

Saint Francis Hospital (SFH) is a church-administered hospital, situated in Katete in the Eastern Province of Zambia in Southern Africa; see Figure 1.1 and Figure 1.2 for the location. The hospital serves the local population of Katete District (240,000 inhabitants) and also receives specialist referrals from all over the Eastern province, which comprises of about 1.7 million people; the population density of the Eastern Province is 24 people per km^2 (Central Statistical Office, 2011). The hospital is mainly concerned for providing treatment to the most vulnerable in society and for providing training to health professionals (SFH, 2012).

Figure 1.1 – Location of Zambia (CIA, 2012)

The hospital was founded in 1948 by a British priest/surgeon with the help of the Anglican Church and has since grown to become one of the largest hospitals in Zambia (Chamberlain, 2005). According to Dr James Cairns, who was the Medical Superintendent of SFH from 1958 to 1996, there were 120 beds in 1958, which has increased to 350 beds, as it is today. Since 1983, the hospital is jointly managed by the Anglican Church and the Roman Catholic Church (Chamberlain, 2005). The School of General Nursing was established in 1953, followed by the School of Midwifery in 1956 (Chamberlain, 2005). The hospital has been led by Dr Shelagh Parkinson (Medical Superintendent) and Ian Parkinson (Manager of Administration) between 1999 and 2011. Since 2012, the SFH Management Board is led by Dr Simon Chisi (Medical Superintendent), while Matthew Mwale is the Manager of Administration.

Figure 1.2 – Location of Katete on a map of Zambia (adapted from CIA, 2012)

The 350 hospital beds are divided into a male medical ward, a female medical ward, a paediatric ward, a maternity ward, a labour ward, a male surgical ward, a female surgical ward, an operating theatre and a special baby care unit (SFH, 2012). Furthermore, there are two recognised training schools for enrolled nurses and enrolled midwives (MSG, 2011), commonly referred to as NTS (Nursing Training School). Hospital personnel (about 400 in total) are predominantly Zambian, but a number of volunteers (doctors and medical students) from overseas regularly help to compensate for the national shortage of clinical staff (SFH, 2012) and to maintain the level of service (MSG, 2011).

SFH is now administered by a joint Anglican - Catholic management board (MSG, 2011). The hospital is fully integrated into the Zambian Health Service and partly funded by the Zambian Government, the Anglican and Catholic Churches and from overseas support groups in the Netherlands and the UK (SFH, 2012). In 2010, the hospital was supposed to receive a monthly grant from the Ministry of Health of 184 million ZMK ($36,570), though only about 70% ($26,000) were received (MSG, 2010). Significant funding is also received from the American government through Catholic Relief Service and AIDS Relief as well as other global funds (via CHAZ) for Malaria, HIV and TB programmes (MSG, 2010).


Figure 1.3 – Main entrance of Saint Francis Hospital. © Mirco Keller.

Accidents and injuries account for the largest proportion of admissions, while malaria and HIV/AIDS follow close behind (SFH, 2012). Each year there are more than 22,000 patients admitted as well as about 110,000 outpatients seen and treated, which includes the treatment of over 7,600 AIDS patients (MSG, 2011). The admissions usually reach a peak during the malaria season (SFH, 2012).

The wastewater disposal system of SFH has been built and developed incrementally since the establishment of the hospital in 1948. Various modifications have been made to the system and new components have been added from time to time, such as converting the pit latrines in the residential areas to flush toilets in 2007 and 2008 (Cullinane, 2009). Except for the “Desktop Study of Sewage Collection, Treatment and Disposal” by Cullinane (2009), the author is not aware of any survey or study that has specifically looked at the wastewater disposal of SFH.

1.2 Outline of the study

This study is the result of a collaboration between HATW (Hands around the World, a British charity) and WEDC. An agreement has been made between Jim Oliver (HATW trustee), Bob Reed (WEDC, supervisor of MSc thesis) and Mirco Keller (WEDC MSc student) in order to carry out this study within the limits of an MSc dissertation. Funding for the study was obtained from the Waterloo Foundation with the initiative from HATW.

After coming to an agreement regarding the scope of the study, the research aim and the research questions were clearly defined, before starting any data collection.

1.2.1 Research aim

To assess the current situation and recommend options for an improved wastewater disposal for the hospital and school (NTS) compound of Saint Francis Hospital in Zambia.

1.2.2 Research questions

1. What are the arrangements, the status and the effectiveness of the current wastewater disposal system and what are its main challenges?
2. What are the expected performance criteria and key factors that are needed for the design of any future wastewater disposal system?
3. What are the principal options for future wastewater disposal facilities and the main criteria for success?

Question 1 will be answered by carrying out a situation analysis of the site, the existing infrastructure and the current arrangements for its operation and maintenance. Question 2 will integrate information gathered in the literature review and in the situation analysis. On the basis of the situation analysis, the literature review, the performance criteria and the key design criteria, Question 3 will be answered by systematically analysing and comparing different technical options.

1.2.3 Target audience

This study is aimed at the hospital management of Saint Francis Hospital specifically, but also any other association concerned with improving the sanitary situation at this hospital. Practitioners or researchers that are particularly interested in excreta disposal problems at hospitals in developing countries may find this case study useful as well. To a certain extent, this study assumes some background knowledge about technical aspects of wastewater systems as well as the general settings that characterise rural district hospitals in Africa.

1.2.4 Scope

This study will focus on the hospital facilities as well as the school (NTS) facilities of Saint Francis Hospital in Zambia exclusively. The residential areas of the hospital campus will not be looked at in depth. The literature review however will also integrate experiences from other hospitals as well as other institutions in developing countries.

1.3 Structure and overview of content

The structure of this report reflects the approach that has been taken during the research project:

Chapter 2 outlines the literature review that was undertaken by the author. It consists of a short methodology section (2.1), the design criteria for wastewater disposal (2.2), a range of technical options for wastewater disposal (2.3), a section about wastewater disposal in hospitals in developing countries (2.4) as well as a brief summary (2.5).

Chapter 3 details the methodology that was used to gather the necessary information to answer the research questions. It comprises a primary section about research methods and tools (3.1), a description of the data collection for this study (3.2) and an explanation of the data analysis (3.3) that was carried out.

Chapter 4 presents the data collected during the study. It is made up of the site conditions (4.1), the hospital buildings and toilet facilities (4.2), the source characterization (4.3), the user requirements (4.4), the existing wastewater disposal system (4.5), institutional aspects (4.7), the relevant legislation (4.8), future plans and population growth (4.9) as well as further information for certain technical options (4.10).

Chapter 5 analyses the data that was collected. It consists of a detailed situation analysis (5.1), a description of common areas in need of improvement (5.2), the key design parameters (5.3), an assessment of the feasibility of a number of options for wastewater disposal (5.4) and a comprehensive description of two technical options as well as the selection criteria (5.5).

Chapter 6 presents the conclusions and recommendations.

2 Literature review

2.1 Methodology

In order to search for literature, the following sources were considered: University Library homepage (Catalogue Plus as well as selected publication databases); WEDC resource centre; Google Scholar search; WHO website; Websites of relevant NGOs; General internet search. Furthermore, some of the WEDC MSc lecture notes (unpublished) proved to be useful as well. Certain published and unpublished literature sources have been directly recommended by WEDC and MSF staff.

The following keywords have been used in the search process: sanitation, wastewater, excreta, sewage, disposal, treatment, on-site, hospital, health care, management. They have been combined in various ways, making use of the following Boolean terms to refine the search: AND; OR; NOT; () (parentheses); " " (quotation marks), and * (the asterisk wildcard).

2.2 Design criteria for wastewater disposal

Selecting an appropriate system type, size and location depends on the wastewater flow and composition, site- and landscape-level assessments, performance requirements and the array of available technology options (USEPA, 2002). While a range of technical options for wastewater disposal are discussed in chapter 2.3, this chapter provides an overview of the design criteria that need to be considered when doing a technical survey for a new wastewater disposal system. The SHTEFIE approach (developed at WEDC) served as a tool to help identifying all the relevant aspects for appropriate design criteria (see Figure 2.1).

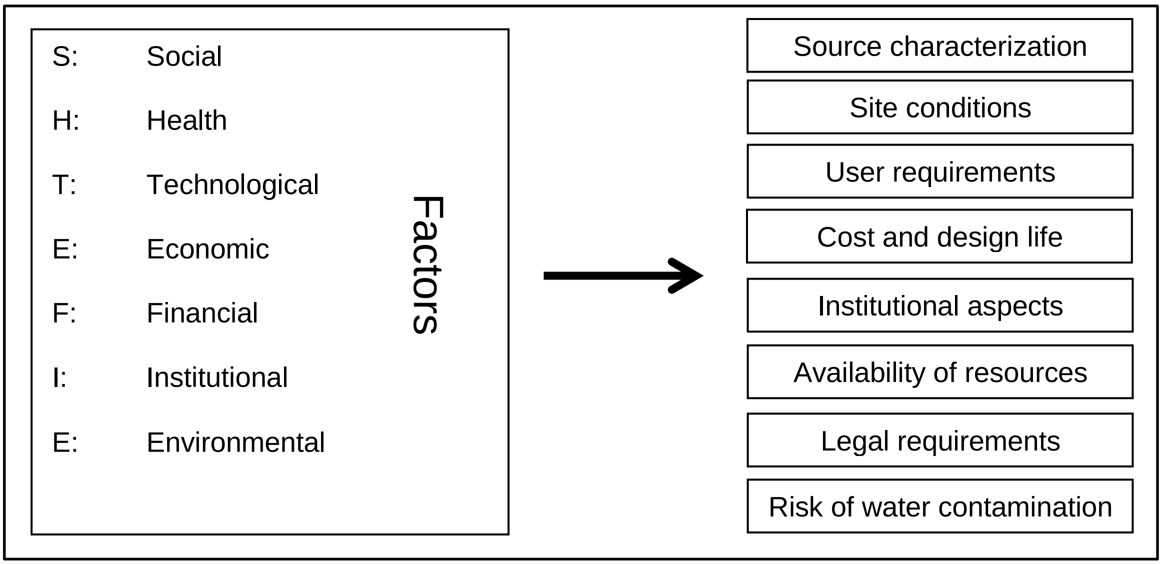

Figure 2.1 – SHTEFIE approach affecting the design criteria

2.2.1 Source characterization

2.2.1.1 On-site systems (pit latrines)

The following factors determine how quickly a latrine pit fills up:

- Number of users per pit
- Sludge accumulation rate per user: 0.04 m^3/person/year for wet latrines, 0.06 m^3/person/year for dry latrines (MSF, 2010)
- Type of anal cleansing materials: if bulky materials are used, this may increase the solids accumulation rate by 30 to 50 % (MSF, 2010)
- Disposal of any other solid materials into the pit

2.2.1.2 Wastewater flow (sewerage systems)

If a sewerage system is in place, the following wastewater flow characteristics need to be determined:

- Daily average wastewater flows
- Minimum and maximum values of wastewater flow
- Temporal/seasonal variations of flow
- Spatial variations of flow within the system

In situations where wastewater flow data are limited or unavailable, estimates should be developed from water consumption records or other information (USEPA, 2002). When using water use records, outdoor water use should be subtracted to develop wastewater flow estimates (USEPA, 2002). Kayombo et al. (2005) suggest taking 85% of the in-house water consumption. Wastewater flow for non-residential establishments can be expressed either in wastewater flow per person or in units that reflect a physical characteristic of the establishment – e.g. per seat, per bed or per m^2. If actual monitoring is not possible, a similar establishment might provide good information, otherwise state and local agencies should be consulted (USEPA, 2002).

Uncontaminated water sources should be identified and eliminated from the wastewater system (USEPA, 2002). It is important to assess the infrastructure for rainwater-runoff, since a separate runoff for rainwater reduces the wastewater flow considerably (Ulrich et al., 2009).

The variability (hourly, daily) of wastewater flow can affect gravity-fed systems by potentially causing hydraulic overloads of the system during peak flow conditions (USEPA, 2002).

2.2.1.3 Wastewater pollutants (sewerage systems)

The type and concentration of wastewater pollutants are important parameters to design an appropriate wastewater disposal system. The qualitative characteristics can be distinguished by their physical, chemical and biological composition.

The following parameters are frequently used to describe the characteristics of wastewater (USEPA, 2002): Total Suspended Solids (TSS); BOD_5; COD; Total Nitrogen (TN); Total Phosphorus (TP); Fats, oils and grease. It is important to know the mass loading per person per day as well as the concentration of each component in the wastewater. The TSS and the BOD_5 are the most important parameters for the design of a wastewater treatment system, while the amount of fats, oils and grease determines the need for a separate grease trap.

The physical composition of the wastewater can be strongly affected by solid waste disposal into the sewers and the type of anal cleansing materials. Wastewater strength from non-residential establishments can vary significantly depending on waste-generating sources present, water usage rates and other factors (USEPA, 2002). Since the wastewater composition can be considerably different from a residential dwelling, USEPA (2002) suggest sampling the septic tank effluent, rather than the raw wastewater. This can more accurately identify and quantify the mass pollutant loads delivered to the components of the final treatment (USEPA, 2002).

If the wastewater is contaminated with chemicals, drugs, acids, alkaline solutions or heavy metals, this may destroy the bacterial population in pit latrines or septic tanks (Jantsch & Vest, 1999). This would affect the digestion of the organic waste, the destruction of germs and pathogens as well as the purification of the wastewater (Jantsch & Vest, 1999). Furthermore, the soil and groundwater will be contaminated by the chemicals, and the danger of spreading diseases will increase (Jantsch & Vest, 1999).

2.2.2 Site conditions

2.2.2.1 Physical nature of the site

Cartographic and topographic surveys and mapping should be conducted – focused on the settlement structure, the topography (elevation) and the site accessibility (Ulrich et al., 2009).

The following issues need to be taken into consideration when doing a detailed site assessment (adapted from Ulrich et al., 2009 and MSF, 2010):

- Topography: slope of ground and suitability for sewerage (a minimum slope of 1.5% is required for black water sewers)
- Available space for treatment and disposal facilities; land ownership and user acceptability of selected sites
- Soil conditions: type; available depth and ease to excavate; infiltration rate; stability; resistance against weight
- Water availability (in case of anal cleansing with water and (pour-) flush latrines)
- Proximity of surface water resources (risk of pollution)
- Level of groundwater table and its seasonal variations (risk of pollution)
- Natural drainage of runoff water; risk of flooding
- Infrastructure for rainwater runoff
- Existing sanitation and wastewater treatment systems

Depending on the existing facilities, the infrastructure and technical standard of the health facility, either a centralised or a decentralised sewerage system can be appropriate. In urban areas it may be possible to directly connect the sewerage system of the health facility to a municipal sewer (Jantsch & Vest, 1999).

2.2.2.2 Receiver site evaluation

In order to assess the capacity of the site to treat and assimilate effluent discharges, a careful and thorough evaluation of the receiver site is necessary. The key criteria for selecting an appropriate type of effluent disposal are presented below.

Groundwater discharge: Firstly, the capacity of the soil to hydraulically accept and treat the expected daily mass loadings of wastewater must be determined (USEPA, 2002); see section 2.3.4.1 for recommended infiltration capacities of different soil types. Adequate drainage of the saturated zone to maintain the necessary unsaturated depth below the infiltrative surface must be ensured to allow oxygenation, re-aeration and prevent effluent surfacing at down-gradient locations (USEPA, 2002). All systems where wastewater infiltrates into the ground need to be sited in order to avoid groundwater contamination (Adams et al., 2008); see section 2.2.8 for details on how to assess the risk of groundwater contamination. Wastewater cannot be applied at rates faster than what the soil can accept, nor can the soil be overloaded with solids or organic matter to the point where soil pores become clogged with solids or a thick development of the biomass (USEPA, 2002). Solids are usually already removed through settling processes; therefore the critical design loadings are the daily and instantaneous hydraulic loading rates and the organic loading rate (USEPA, 2002).

Surface water discharge: Surface water discharging systems typically consist of a treatment plant which discharges the final effluent to a surface water body. The receiving water body needs to be assessed with regard to water quality, flow volume and location, including groundwater quality, use and level (Ulrich et al., 2009). Furthermore, the designated use of the surface water source and the sensitivity of the aquatic ecosystem to eutrophication must be considered (USEPA, 2002). The important design boundaries for such a system are the inlet to the treatment plant and the outfall to the surface water (USEPA, 2002). Typically, the discharge permit and the performance history of the treatment process establish the limits of mass loading that can be handled both at the inlet and the outlet (USEPA, 2002). These loadings are often expressed in terms of daily maximum flow and pollutant concentrations. The effluent limits and the wastewater characteristics establish the extent of treatment needed before final discharge (USEPA, 2002).

Atmospheric discharge: In certain situations, evapotranspiration systems can be considered for the disposal of the final effluent; see section 2.3.4.2 for further information. While different types of systems exist, the primary design boundary is always the evaporative surface (USEPA, 2002). The mass loading (volume per unit area of boundary surface) controls the design, while the loadings are determined by the ambient climatic conditions expected (USEPA, 2002).

2.2.2.3 Climate

The following climatic factors need to be considered (MSF, 2010):

Precipitation pattern: The amount of rainfall can strongly affect the amount of surface runoff and increase the quantity of wastewater flow. This is especially important to consider if rainwater is collected in the same sewerage system with the black water.

Temperature: The air temperature can have a significant impact on the effectiveness of certain treatment processes. Furthermore, it can affect the transmission of vector-borne diseases.

Wind direction: The main direction into which the wind is blowing needs to be considered in order to avoid any nuisance of inhabitants due to unpleasant odour.

2.2.3 User requirements

The number of potential users and their habits regarding sanitation practices needs to be assessed carefully (Ulrich et al., 2009). The following socio-cultural and religious factors need to be considered (MSF, 2010):

- Need for separation of the sexes
- Need for privacy
- Position (sitting or squatting)
- Method of anal cleansing, material used, its disposal
- Menstruation (material used, its disposal or being washed and reused)
- Particular orientation of the latrines
- Taboo locations and/or practices
- Acceptability of emptying a latrine pit

2.2.4 Legal requirements and guidelines

Guidelines on environmental health in health care should be used, together with existing national standards and guidelines, for creating targets, policies and procedures to be used in each health-care setting (Adams et al., 2008).

2.2.4.1 Legal requirements

Wastewater discharge standards and environmental protection regulations need to be gathered and adhered to (Ulrich et al., 2009). The design of any wastewater treatment system must comply with the rules and regulations of the permitting entity (USEPA, 2002). It is possible that the relevant authorities in certain countries forbid or enforce certain methods of excreta disposal (MSF, 2010).

2.2.4.2 Guidelines

The following guidelines for sanitation in health establishments are based on the WHO standards - *Essential environmental health standards in health care* (Adams et al., 2008) and the Médecins Sans Frontières standards - *Essential water and sanitation requirements for health structures* (MSF, 2010).

Sufficient number of toilets: One toilet per 20 users for inpatient settings and at least four toilets per outpatient setting (one for staff, and for patients: one for females, one for males and one for children) are recommended.

Good accessibility: The toilets should be located between 5 and 30 m from all users.

Technically appropriate: Pit latrine / VIP latrine / Pour-flush latrine / Flush toilet

Appropriate for users: Culturally and socially appropriate; separate facilities for staff and patients; separation between men and women; toilets for patients should be easy to use by physically impaired patients; special children's toilets should be provided; facilities for the disposal or washing of menstrual cloths should be provided.

Safety concerns: Toilets should be located and designed (lockable by user) in order to minimize the risk of violence. Toilets and their access routes should be lit at night.

Hand washing facilities: Water points with soap and adequate drainage should be provided at the exit of all toilets.

Prevent water contamination: Pit latrines and subsurface wastewater infiltration systems should be at least 30 m away from water resources. There should be at least 1.5 m between the bottom of the infiltration system and the groundwater table.

2.2.5 Cost and design life

Costs are always a critical concern for the owner; capital (construction) costs as well as recurrent costs (operation and maintenance) should be estimated, and total costs over time should be calculated (USEPA, 2002).

The following costs need to be considered (Ulrich et al., 2009):

Land, materials, labour, supervision (including optional planning), operation (electricity, water, service provision) and maintenance (repairs, desludging, sludge treatment).

Cost-recovery can be achieved with financial contributions from residents, public authorities and international donors (Ulrich et al., 2009). A possible tariff structure should be based on a completed assessment of the users' willingness to pay (Ulrich et al., 2009). The intended design life of the system is often closely related to its financial implications. An expensive system might last for long and have low recurrent costs, while a cheaper system might have a shorter design life but incur higher recurrent costs.

2.2.6 Institutional aspects

2.2.6.1 Operation and maintenance

Maintenance is a key element in the use of excreta disposal facilities (MSF, 2010). The owner of the system should have both the ability and the willingness to perform operation and maintenance tasks if the system is to perform satisfactorily (USEPA, 2002). To ensure that clean and functioning toilets are available at all times, a cleaning and maintenance routine needs to be in operation (Adams et al., 2008).

Maintenance, repair and eventual replacement of environmental health facilities need to be taken into account while they are being designed and built; planning and budgeting issues for O&M need to be considered from the beginning of a programme (Adams et al., 2008; Scott, 2012). The operation of waste management structures in health facilities will require considerable financial resources since hygienic and environmental protection costs money (Jantsch & Vest, 1999).

The following key factors for sustainable O&M of sanitation systems in public institutions have been found (adapted from Adams et al., 2008 and Müllegger & Freiberger, 2010):

- Responsibilities for O&M must be clearly defined right from the beginning.
- Appropriate expertise for O&M needs to be provided.
- The institution must see the benefit of the system and ideally gain extra income with it.
- All stakeholders should be involved in the planning from the beginning of the project; critical design decisions should be made by the users.
- Users need to be sensitized and trained before and during the construction of the system.

2.2.6.2 Waste management plan and monitoring

The institutional basis of any waste management at health facilities is the waste management plan, which is itself part of the hygiene plan (Jantsch & Vest, 1999). All standards, procedures, regulations and guidelines regarding waste management aspects need to be listed in the waste management plan (Jantsch & Vest, 1999). For the management, the plan is the instrument for monitoring, supervising and organising all waste management activities whereas for the staff it will provide advice and guidance for their waste management practice (Jantsch & Vest, 1999).

The generation of the different types of waste should be monitored on a regular basis, as it will indicate the success or failure of the waste management activities and will encourage people to increase their efforts (Jantsch & Vest, 1999). Monitoring results will also give important data for administration and general planning of waste management activities (Jantsch & Vest, 1999).

2.2.6.3 *Implementation*

Often, achieving appropriate standards will not be possible in the short term. Steps should be taken to prioritize improvements and to work in a phased way so that the most urgent problems can be identified and addressed immediately, while other benefits will be subsequently achieved (Adams et al., 2008). Establishing a proper waste management system for health facilities can be seen as an on-going process (Jantsch & Vest, 1999).

It is very important to ensure that the whole community supports the project; sometimes it can be helpful to formalise the overall process by signing a Memorandum of Understanding (MoU) (Ulrich et al., 2009).

2.2.7 Availability of resources

Financial resources: The availability of financial resources is crucial for the construction, operation and maintenance of sanitation facilities. Material and labour costs have an influence on the type and quantity of latrines (MSF, 2010).

Materials and tools: If building materials and tools are locally available, this will have an impact on the construction time and costs, but also on the environment (MSF, 2010).

Human resources: The availability of skilled and experienced local personnel for the construction as well as for maintenance and repair of the facilities needs to be considered when choosing technology (Adams et al., 2008).

2.2.8 Assessing risk of water source contamination

2.2.8.1 *On-site sanitation*

There are three ways of reducing the risk of groundwater sources becoming polluted by latrine infiltration systems (Lawrence et al., 2001): Vertical separation within the unsaturated zone, lateral separation between the pollution source and the supply point, and vertical separation below the water table.

Lawrence et al. (2001) recommend the following process to assess the risk of microbiological contamination of groundwater via aquifer pathways where groundwater supplies exist and only on-site sanitation (including septic tanks and all types of pit latrines) is being installed:

Step 1: Collect background information: Determine the typical minimum depth to the water table; Collect information on the types of sanitation system to be used; Collect information on the design and construction of groundwater supplies in the area (screen depth below water table, flow rate); Collect information on soil types (in the unsaturated zone as well as in the saturated zone).

Step 2: Assess attenuation within unsaturated zone: If dug wells or boreholes are screened at the water table, it is necessary to assess whether the unsaturated zone can provide sufficient attenuation (see Lawrence et al. (2001) for the relevant table). If the risk is low or very low, any dry-type latrine can be used. If no dug wells or boreholes are screened at the water table or if the risk is significant, proceed to *Step 3*.

Step 3: Assess attenuation with depth below water table: If the screen on existing boreholes is sufficiently deep to attenuate pathogens within the saturated zone (see Lawrence et al. (2001) for the relevant table), any type of on-site sanitation system can be installed. If the screen is not sufficiently deep, proceed to *Step 4*.

Step 4: Assess attenuation with lateral separation in aquifer

If it is possible to provide sufficient horizontal separation between water supply and on-site sanitation to attenuate pathogens (using Table 2.1), any type of latrine can be installed.

Table 2.1 – Minimum separation between pollution points and groundwater sources (Scott, 2012)

Soil/Rock type	**Approximate minimum distance (m)**
Silt	10*
Fine silty sand	15
Weathered basement (not fractured)	25
Medium sand	50
Gravel	500
Fractured rocks	Not feasible to use horizontal separation as protection
Note: *10m is the minimum distance an infiltration system should be from a water source because of the risk of pollution from localised pollution pathways such as fissures, cracks and disturbances caused by construction	

If it is not possible to provide sufficient horizontal separation, the following options can be considered, though a residual risk always remains:

- Investigate special sanitation design options that reduce risk
- Examine appropriateness of installing new (deeper) water supplies
- Treat water supplies
- Invest in off-site treatment
- Accept risk but investigate an increased level of monitoring

2.2.8.2 Off-site sanitation

If large-scale sewerage systems with wastewater treatment and disposal (e.g. waste stabilization ponds, aerated lagoons or constructed wetlands) are implemented, different considerations have to be made for assessing the risk of water source contamination.

Leaking sewers may significantly contribute to microbiological and nitrate contamination of groundwater and therefore may represent a significant risk where groundwater is exploited for domestic supply (Lawrence et al., 2001). Furthermore, if the treatment facilities are poorly operated and managed, this can lead to the discharge of inadequately treated wastes into the environment (Lawrence et al., 2001). In most cases this will be into surface water bodies, although groundwater may become contaminated subsequently (Lawrence et al., 2001).

Some forms of off-site sanitation such as waste stabilisation ponds may be prone to leaching of both microbiological and chemical contaminants. Attention must therefore be paid to the potential for groundwater contamination and it must be ensured that systems are operated and designed with groundwater protection needs in mind (Lawrence et al., 2001).

2.3 Technical options for wastewater disposal

In this chapter, a range of options for wastewater treatment and disposal are presented. The technical features of each option are explained briefly and its appropriateness is discussed. More complex options (as being used in wastewater treatment plants in developed countries) have deliberately not been considered, since public institutions in developing countries could not cope with the financial and technical requirements and the needs for O&M.

2.3.1 Toilets

2.3.1.1 Simple pit latrine

A simple pit latrine (see Figure 2.2 for an illustration) consists of a slab over a pit which may be two metres or more in depth, a squat hole in the slab or a seat is provided so that the excreta fall directly into the pit (Franceys et al., 1992). It is simple and cheap to build and needs no water for operation, but it can cause considerable fly nuisance and smell (Franceys et al., 1992). The slab and the shelter can be re-used after a pit is filled up (Jantsch & Vest, 1999).

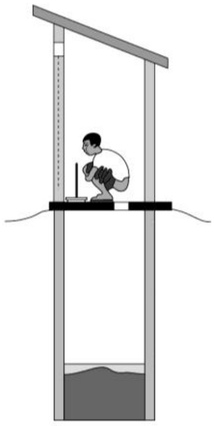

Figure 2.2 – Simple pit latrine (image courtesy of WEDC. © Ken Chatterton)

Once the contents in a pit reach 0.5 m below the top, it should either be excavated or filled with earth and a new pit should be dug (Jantsch & Vest, 1999). If the latrine is not excavated once it is full, it can also be used to dispose of infectious material or used needles and sharps, since there is no danger of access to the excreta (Jantsch & Vest, 1999). If the ground consists of hard rock, if the water table is very close to the surface or if the area is prone to flooding, it may be advantageous to raise the pit above the ground (MSF, 2010; Scott, 2012). The raised pit lining can be surrounded with a mound of soil. Part of the lining can be left porous so that liquids can percolate into the mound and then into the top soil (Scott, 2012).

Basic design features (adapted from Scott, 2012):

Size: Pits are typically 2.4 – 4 m deep and 1 – 1.5 m wide; the larger the pit, the longer it will take to become full. The total volume (V) of a pit can be calculated as follows (MSF, 2010): **V = (N x S x Y) + 0.5A**, (N = number of users; S = solids accumulation rate in m^3/person/year (use 0.04 for wet latrines, 0.06 for dry latrines); Y = lifetime of the latrine in years; A = pit base area). The effective pit volume may be increased by 30 to 50% if bulky anal cleansing materials are used (MSF, 2010).

Construction: The top 0.5 m of a pit must always be lined; depending on local soil conditions and emptying practices, the rest might also need to be lined. The cover slab is commonly flat with a hole near the centre and it is placed directly on top of the pit lining about 15 cm above the surrounding ground level. The cover slab is surrounded by a mound of soil to seal the space between the lining, the slab and the surrounding soil. The superstructure provides privacy for the users and the design of it can be adapted to suit the requirements of the users. Specially designed children's pit latrines should be implemented, especially in health structures where lots of children are present (MSF, 2010).

Criteria for appropriateness (adapted from Feachem & Cairncross, 1978 and Scott, 2012):

- Appropriate for self-help programmes (as family latrines for households) in which householders are responsible for their own sanitation.
- Low population density as well as sufficient place to dig pits is necessary.
- Low water table is preferable (high water table makes construction difficult).
- Ground needs to be dug easily (no rocky ground and no loose sandy soils).
- No expensive materials, tools or skills required for construction and O&M.

2.3.1.2 Composting latrine

Composting latrines are dry toilets which operate without the need for flushing water (Berger, 2011). If the moisture content and the chemical balance in the tank are controlled, the mixture will decompose to form a good soil conditioner and pathogens will be killed in the dry alkaline compost, which can be removed for land application as a fertilizer (Franceys et al., 1992). The recommendations of how long the compost should be stored before usage range from as little as 10 months up to 2 years (Scott, 2012). In order to produce valuable humus, careful operation is essential, the urine has to be collected separately and ash or organic matter must be added regularly (Franceys et al., 1992).

Criteria for appropriateness:

- Strong commitment of the users to operate the system carefully and accept the responsibility for its operation is needed (Berger, 2011).
- Removal of the residues of excreta must be socio-culturally acceptable (MSF, 2010).
- Regular maintenance in private or public use is critical to ensure that the facility is operating well (Berger, 2011).
- Not appropriate if water is used for anal cleansing or where people bath in the toilet cubicle (Scott, 2012).
- Not suitable for large public institutions.

2.3.1.3 Pour-flush latrines

A trap is fitted to the collection pan to provide a water seal, which is cleared of faeces by pouring in sufficient quantities of water (Franceys et al., 1992). The water seal prevents odours, flies and mosquitoes from getting out of the pit (Scott, 2012).

There are three basic types of pour-flush latrines (Scott, 2012):

<u>*Simple pour-flush latrine*</u>: The water-seal pan is fitted directly into the cover slab of the pit. The pan can be designed so that it can be removed to allow emptying of the pit.

<u>*Offset pour-flush latrine*</u>: The pit is separated from the toilet building; a short length of typically 100-150 mm diameter pipe leads from the toilet pan to the seepage pit (see Figure 2.3 for an illustration). Once the pit is full, a second pit could be dug and the discharge pipe diverted to it; in the meantime, the first pit can be safely emptied and reused. They are more expensive to build and require more water to flush than simple pour-flush latrines.

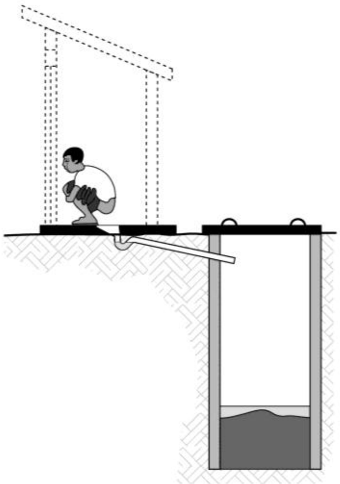

Figure 2.3 – Offset pour-flush latrine (Image courtesy of WEDC. © Ken Chatterton)

<u>*Twin pit offset pour-flush latrine*</u>: If it is not feasible to dig a deep pit (due to high water table, unstable soil or very hard rock), it is often easier to dig two shallow pits. The pits are connected to the water-seal pan by short lengths of pipe that converge at an inspection chamber. The pits are used alternatingly; as soon as the first one is full, the second one can start to be used while the first one is being emptied. The amount of water required is slightly higher than for a single offset pour-flush latrine because the pipe is generally longer and includes bends.

Pour-flush water-seal pans can also be used in conjunction with a septic tank or a sewerage system. The different treatment and disposal options that they can be used with are described in the following chapters (section 2.3.2 to 2.3.4).

<u>*Criteria for appropriateness:*</u>

- Pour-flush latrines can be used for households as for public buildings and health structures (MSF, 2010).
- A reliable (even if limited) water supply must be available in the direct neighbourhood (Franceys et al., 1992; MSF, 2010).
- Unsuitable if solid anal cleansing materials such as newspaper, corn cobs, leaves, sticks or stones are used (Franceys et al., 1992; Scott, 2012).
- Most suitable if water or soft toilet tissues is used for anal cleansing (Scott, 2012).
- Should only be considered where the system is technically and socio-culturally acceptable (MSF, 2010).

- Especially for twin pit pour-flush latrines, considerable time and effort is required to introduce the technology and its operation and maintenance to families (Scott, 2012)

2.3.1.4 Cistern flush toilets

The pan of a water closet (WC) provides a water seal; by discharging a cistern (usually about 10 litres), the excreta are flushed into a drain (see Figure 2.4 for an illustration). The discharge then flows along a system of sewers to the treatment works (Franceys et al., 1992).

<u>*Criteria for appropriateness:*</u>

- Most convenient form of sanitation.
- High construction costs (Franceys et al., 1992).
- Efficient infrastructure required for construction, operation and maintenance.
- A reliable water supply is crucial – a minimum of 70 litres per person per day is recommended (Franceys et al., 1992).

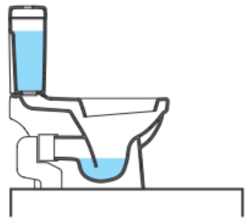

Figure 2.4 – Flush toilet (Tilley et al., 2008)

2.3.1.5 Urinals

Urinals are usually simple structures designed to collect urine and channel it to a disposal point. If possible, the collected urine should be diverted into a wastewater treatment and disposal system, otherwise a simple soak pit can be used (Scott, 2012). The provision of urinals (for males – occasionally for females too) reduces the fouling of cubicles and reduces the number of cubicles required (Scott, 2012).

2.3.2 Collection and removal of wastewater

A removal system should be able to evacuate wastewater so as to avoid stagnant water and to channel it to the treatment / disposal site without contaminating the local environment (MSF, 2010). Wastewater drainage from health-care settings should be built and managed to avoid contamination of the health-care setting or the broader environment (Adams et al., 2008). It should be gently sloped (minimum 1% for grey water and 1.5% for black water) and preferably cemented (MSF, 2010). Wastewater from hospitals should always be drained in closed pipes, since it should not come into contact with anybody (Jantsch & Vest, 1999).

2.3.2.1 Open channels (preferably covered)

This is the most simple and least costly technique, but it entails maintenance problems (MSF, 2010). Furthermore, it smells, promotes insect breeding and remains a health hazard (Ulrich et al., 2009). Open channels should only be used for drainage of runoff water or for evacuation of sullage over short distances (MSF, 2010). For health-care facilities, all open wastewater drainage systems should be covered to avoid the risk of disease vector breeding and contamination (Adams et al., 2008).

2.3.2.2 Conventional gravity sewerage

This is the most effective way of removing all kinds of wastewater, but also the most expensive one (MSF, 2010). Various types of pipes (e.g. PVC, polyethylene cement) with a minimum diameter of 100 mm may be used; the pipe diameter should be adequate for the flow and the pipes should be buried (MSF, 2010). In order to clean the system, a minimum diameter of 200 mm is recommended; furthermore a minimum velocity of 0.5 m/s is required to avoid solids deposits (Ulrich et al., 2009). Special care needs to be taken at crossing places of vehicles and big animals; manholes and collection boxes should be included for long and/or complex drainpipe systems (MSF, 2010).

In *combined gravity sewerage*, domestic wastewater is collected together with rain and runoff water in a sewerage system. Since the system must be designed to cope with peak flows, diameters in the range of 300 mm to 1,200 mm are often required (Ulrich et al., 2009).

In *separated gravity sewerage*, storm water is not collected together with domestic wastewater, but drained separately. Therefore, the wastewater treatment system does not have to be oversized and the biology will be kept stable (Ulrich et al., 2009).

2.3.2.3 Small-bore systems

Small-bore systems receive the effluent from individual or shared household septic tanks. As coarse solids are removed in the septic tank, only the liquid part of sewage enters the sewerage system (Ulrich et al., 2009). No self-cleansing flow-velocity is required and as a result the system can be operated with less water and the pipes can have smaller diameters – minimum 100 mm (Ulrich et al., 2009). It can be installed very close to the surface in all types of terrain and even allow inflective gradients. Clogging and blocking of pipes is very unlikely and the amount of maintenance needed on the piping system is minimal (Ulrich et al., 2009).

2.3.3 Treatment systems

2.3.3.1 Septic tank

A septic tank is an underground watertight settling chamber into which raw sewage is delivered. The sewage is partially treated in the tank by separation of solids and decomposition by bacteria (Franceys et al., 1992; Jantsch & Vest, 1999). Since organic solids are partially digested in the septic tank, this can reduce the sludge and scum volume by as much as 40 per cent (USEPA, 2002). To a large extent, germs and pathogens are destroyed in the tank (Jantsch & Vest, 1999). Grey and black water may be treated in the same septic tank and soakaway system, but this requires a larger septic tank than one used for black water alone (Adams et al., 2008). For big infrastructures, it is therefore suggested to treat only the black water in the septic tank (MSF, 2010). Apart from the removal and digestion of solids, septic tanks also provide some peak flow attenuation (USEPA, 2002). Septic tanks may be used alone or in combination with other, secondary treatment processes (USEPA, 2002). The final effluents from septic tanks are commonly disposed of by subsurface wastewater infiltration systems (Scott, 2012), occasionally evapotranspiration systems are used. Disposing it directly into a surface water body is not recommended in most cases.

Basic design features:

Location and access: Septic tanks and soakaways should not be located too close to buildings, water sources or to trees whose growing roots may damage them (Feachem & Cairncross, 1978). Convenient access to the septic tank is necessary for pumping out the sludge, observing baffle walls and for servicing the effluent screen (USEPA, 2002).

Residence time: The important factor to achieving good removal of solids is maintaining quiescent conditions, which is accomplished by providing a long wastewater residence time in the septic tank (USEPA, 2002). This ensures calm conditions and allows sufficient time for the solid material to settle. Tank *volume*, *geometry* and *compartmentalization* affect the residence time (USEPA, 2002).

Volume:

Septic tanks must have sufficient volume to provide an adequate hydraulic residence time for sedimentation (USEPA, 2002). The residence time of the wastewater should ideally be 24 hours or more (Jantsch & Vest, 1999). Since sludge and scum may occupy a large part of the volume, this needs to be considered when calculating the size of the tank.

The total space within a septic tank can be divided into three parts: Clear liquid retention volume (A); Storage for sludge and scum (B) and Ventilation space (C). The following method to determine A, B and C has been developed by WEDC by synthesizing the results produced by other formulae being used (Scott, 2012):

Firstly, the retention time has to be determined, using Table 2.2.

Table 2.2 – Recommended retention times (Scott, 2012)

Daily wastewater flow (Q)	**Retention time T (hours)**
Less than 6 m^3/day	24
Between 6 and 14 m^3/day	33 – 1.5Q
Greater than 14 m^3/day	12

Secondly, A can be calculated using the formula: **A = Q x T/24**

Thirdly, B can be estimated using the formula: **B = P x N x F x S_d** (P = number of people served; N = number of years between Desludging; F = factor for sludge digestion rate (see Table 2.3); S_d = annual rate of sludge and scum production (m^3/person/year); S_d can be estimated to be 0.025 m^3/person/year for toilet wastes only; and 0.040 m^3/person/year for toilet wastes including grey water (Scott, 2012)).

Table 2.3 – Value of the sludge digestion factor F (adapted from Scott, 2012)

Years between Desludging	**Average air temperature**		
	Greater than 20°C all year	Between 10 and 20°C all year	Less than 10°C in winter
1	1.3	1.5	2.5
2	1.0	1.15	1.5
3	1.0	1.0	1.27
4	1.0	1.0	1.15

Fourthly, the ventilation space (C) is equal to 0.3 m time the tank surface area.

Total volume of septic tank = A + B + C

Geometry: Tanks with length-to-width ratios of 3:1 and greater have been shown to reduce short-circuiting of the raw wastewater across the tank and improve suspended solids removal (USEPA, 2002). Tanks with shallower liquid depths (amongst tanks of equal liquid volumes) better reduce peak outflow rates and velocities due to the larger surface area (USEPA, 2002).

Compartmentalization: It is best to build a septic tank with two compartments (see Figure 2.5), the first one being twice as big as the second (Jantsch & Vest, 1999; Scott, 2012). Compartmentalized tanks or tanks placed in series provide better suspended solids removal than single-compartment tanks alone (USEPA, 2002).

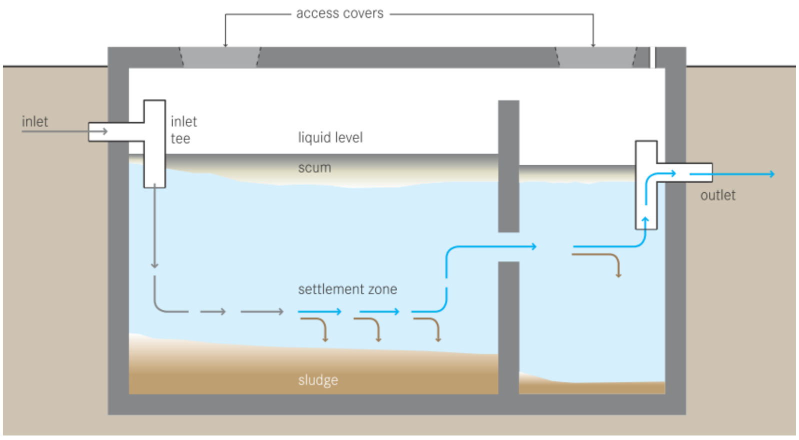

Figure 2.5 – Treatment processes in a septic tank (Tilley et al., 2008)

Dimensions (Scott, 2012): The depth of liquid from the tank floor to the bottom of the outlet pipe should be at least 1.2m and preferably 1.5m or more. The width of the tank should be at least 0.6m. The width of the tank should be half the length of the first compartment and the width of the second compartment should be equal to its length. In larger tanks the base often slopes towards the inlet end of the tank.

Inlets and outlets: A 2'' to 3'' (5 to 8 cm) drop across the tank should be provided (USEPA, 2002). Both the inlet and outlet are commonly baffled. Plastic sanitary tees are recommended for smaller units serving 1 or 2 families, while for larger units the outlet tee piece should be replaced by a weir and scum board plate (Scott, 2012). The use of a removable, cleanable effluent screen connected to the outlet is strongly recommended (USEPA, 2002).

Watertightness: Watertightness of a septic tank is critical to the performance of the entire wastewater system; leaks, whether exfiltrating or infiltrating, are serious and need to avoided as much as possible (USEPA, 2002).

Desludging and maintenance: The recommended periods between the desludging of septic tanks range from 1 to 5 years, depending on tank size, number of users, as well as habits and appliances (Feachem & Cairncross, 1978; Grant & Moodie, 1997; USEPA, 2002). Regular inspections should be performed to observe sludge and scum accumulations, structural soundness, water tightness and condition of the baffles and screens (USEPA, 2002).

Grease trap: The accumulation of grease can be a problem in certain institutions with large volumes of kitchen wastewaters, since it can clog sewer lines and inlet and outlet structures of septic tanks (USEPA, 1980). Grease traps, which are small flotation chambers where grease is retained, can remove it from the wastewater prior to flowing into a septic tank (USEPA, 1980). They should be located close to the source of the wastewater and must to be cleaned regularly and the grease and solids removed (MSF, 2010).

Criteria for its appropriateness:

- Can be used in nearly all onsite systems regardless of daily wastewater flow rate or strength (USEPA, 2002).
- Can be appropriate for individual households and for institutions such as schools or hospitals (Jantsch & Vest, 1999; Adams et al., 2008; Scott, 2012).
- Appropriate for situations where the volume of wastewater is too large for disposal in pit latrines, and waterborne sewerage is uneconomic and unaffordable (Scott, 2012).
- Work much better if water is used for anal cleansing instead of stones, sticks or heavy paper (Feachem & Cairncross, 1978).
- Can be operated with pour-flush toilets or flush toilets, but a reliable and ample water supply is required (Franceys et al., 1992).
- Not suitable if strong disinfectants or alkalis are discharged, since it may severely hinder its operation (Feachem & Cairncross, 1978).
- Enough financial means must be available, since it is quite expensive to construct (Franceys et al., 1992).
- The sludge needs to be removed periodically (Franceys et al., 1992).

2.3.3.2 Waste Stabilization Ponds

Waste Stabilization Ponds (WSPs) are artificial lakes which provide wastewater treatment through natural processes (Ulrich et al., 2009). The wastes flow by gravity from one pond to the next. The system should comprise a number of successive ponds to purify the sewage (Prüss et al., 1999). Oxygen is made available via large surface areas which allow it to enter the water more easily (Jantsch & Vest, 1999).

Ponds are often rectangular in plan; depths vary from 1 to 5 m, depending on the type of pond (Reed & Skinner, 2011). Since the rate of oxidation is slow, long hydraulic retention times are required (about 30 to 50 days) and large areas of land are therefore required (Reed & Skinner, 2011). The more lagoons in line are used, the better the quality of the effluent becomes (Jantsch & Vest, 1999). Lagoon systems are usually built in pairs (in parallel), so that the anaerobic and facultative ponds can be drained and the sludge dug out every few years (Jantsch & Vest, 1999).

There are three main types of ponds which are arranged in series as described below:

Anaerobic pond: This is needed if pre-treatment of raw wastewater or settlement of domestic wastewaters is required (Reed & Skinner, 2011). If the wastewater has already been through a septic tank, anaerobic ponds are usually not required (Feachem & Cairncross, 1978). They are typically between 2 and 5 m deep and have a retention period of 1 to 5 days (Reed & Skinner, 2011). Solids settle out at the bottom and are digested anaerobically (Jantsch & Vest, 1999). Desludging is required when the pond is one third full of sludge by volume (Kayombo et al., 2005) – sludge accumulates at a rate of about 0.03 to 0.04 m^3/person/year (Reed & Skinner, 2011). The two design parameters are retention time and volumetric organic load (Ulrich et al., 2009). Ponds with sufficient, integrated sludge storage make sludge-removal intervals of over 10 years possible (Ulrich et al., 2009).

Facultative pond: The facultative pond follows the anaerobic pond (Reed & Skinner, 2011). It is used principally for BOD removal - in the upper layers oxidation of organic matter takes place, while any remaining solids settle to the bottom and are digested anaerobically (Reed & Skinner, 2011). Oxygen in the upper layers is provided via the water surface and from algae via photosynthesis (Ulrich et al., 2009). Facultative ponds are shallow (1 to 2 m), but larger than anaerobic ponds since a retention time of 20 to 40 days is required (Jantsch & Vest, 1999; Reed & Skinner, 2011). Treatment efficiency increases with longer retention times, while the number of ponds is of only relative influence (Ulrich et al., 2009). Sludge removal is only required every 10 to 20 years (Reed & Skinner, 2011). The two design parameters are organic surface load and hydraulic retention time – the maximum organic load depends on the ambient temperature (Ulrich et al., 2009).

Maturation ponds: These follow the facultative pond and further reduce the numbers of faecal bacteria, BOD and suspended solids (Reed & Skinner, 2011). Maturation ponds allow oxygen and sunlight to kill pathogens and make the liquid safe for discharge into a river or for the irrigation of crops (Jantsch & Vest, 1999). Three or more ponds - approximately 1 to 1.5 m deep - are provided in series, having a hydraulic retention time of between 3 and 5 days in each pond (Reed & Skinner, 2011). It is possible to remove 99.99% of faecal coliforms in this way – the bacteriological performance is controlled by the size and number of maturation ponds (Reed & Skinner, 2011).

Figure 2.6 shows the order and arrangement of WSPs, the sludge accumulation as well as the importance of oxygen supply.

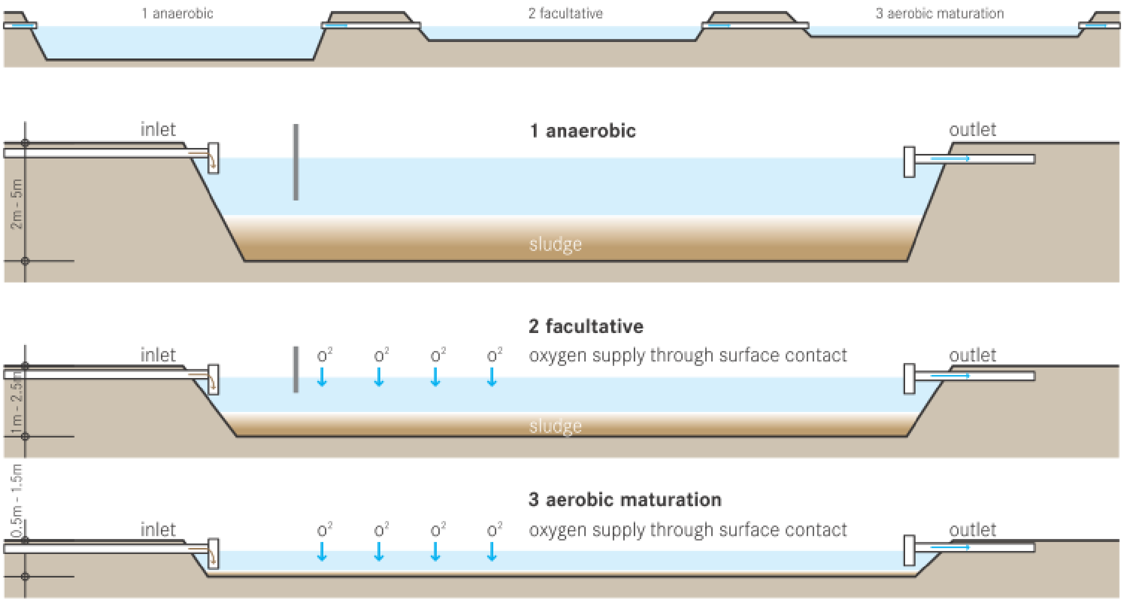

Figure 2.6 – Illustration of Waste Stabilization Ponds (Tilley et al., 2008)

Criteria for appropriateness:

- Very effective in sunny climates (Jantsch & Vest, 1999).
- A large area of land is required for effective operation (Reed & Skinner, 2011).
- Very effective in the removal of faecal bacteria (Reed & Skinner, 2011).
- Unpleasant odours may be released and the breeding of insects may occur.
- Suitable for small community, institution or a large city (Feachem & Cairncross, 1978).
- Construction and maintenance is cheap and simple (Reed & Skinner, 2011).

2.3.3.3 Aerated lagoons

A more advanced option of WSPs are aerated lagoons. If insufficient land is available or the climatic conditions are less favourable for WSPs, this option may be more appropriate (Reed & Skinner, 2011). Oxygen is injected into the wastewater by electrically-powered floating surface aerators, diffusers or submerged air pipes (Jantsch & Vest, 1999). BOD removal is about 90% with a retention time of 2 to 6 days, and conditions in the lagoons are principally aerobic (Reed & Skinner, 2011). To allow settlement of the suspended solids, the aeration device is switched off for a short period, so that the water can run off near the surface (Jantsch & Vest, 1999). This form of treatment is less effective than WSPs at removing pathogens; usually only about 90 – 95% of faecal bacteria are removed (Reed & Skinner, 2011).

Criteria for appropriateness:

- Sufficient land needs to be available, though less than for Waste Stabilization Ponds (Jantsch & Vest, 1999; Reed & Skinner, 2011).

- A stable power supply is required (USEPA, 2002).
- Routine maintenance is crucial, requires semiskilled operators (USEPA, 2002).
- Substantial financial means for O&M (energy costs and semiskilled operators) need to be available (USEPA, 2002).

2.3.3.4 Constructed wetlands

Constructed wetlands are shallow pans with an impermeable bottom layer in which wetland plants are growing (Jantsch & Vest, 1999). The wastewater flows through the wetland and the organic material is decomposed by bacteria populating the roots of the plants, while the plants purify the water and live on the nutrients generated by the decomposition process (Jantsch & Vest, 1999). The effluent leaving the wetland is fit for irrigation or can be discharged into a river (Jantsch & Vest, 1999). Some danger may result from mosquitoes and other insects breeding in the wetlands and lagoons; it may help to keep some fish in the lagoons if the water quality is sufficiently high (Jantsch & Vest, 1999). The wastewater must be pre-treated so that suspended solids are removed before it enters the treatment unit (Reed & Skinner, 2011). If it is used for secondary treatment and the wastewater carries inorganic and organic toxic pollutants, this can affect the microbial processes and it may therefore not produce the desired effluent quality (Gopal, 1999). The land requirement per unit volume of wastewater to be treated varies from 10 to 20 persons' domestic wastewater per hectare (Gopal, 1999).

In developing countries there is yet hardly any evidence with constructed wetlands on a reasonable scale, and their efficiencies and management requirements have yet to be examined (Gopal, 1999). Furthermore, the treatment process is complex and not yet fully understood; calculating the proper dimensions and treatment characteristics only make sense if the exact required parameters are known, which is hardly ever the case (Ulrich et al., 2009).

2.3.3.5 Anaerobic digestion / Biogas plant

A completely different decomposition process for organic matter is anaerobic digestion by bacteria which do not need oxygen to survive, but generate methane gas while decomposing the organic matter (Jantsch & Vest, 1999). It is an alternative to centralised wastewater treatment systems and also an excellent technology for organic sludge treatment - the sludge production is five times less compared to aerobic systems (Mang & Li, 2010). Biogas sanitation systems do not provide a complete pathogen removal, are temperature dependent, have a variable performance and there is a risk of explosion (Mang & Li, 2010). Furthermore, they are very expensive to build and difficult to operate (Scott, 2012)

Criteria for appropriateness:

- Experienced construction and design staff required (Mang & Li, 2010).
- Maintenance needs to be carried out by well-trained technicians (Mang & Li, 2010).
- Commitment to recycling organic wastes is crucial (Scott, 2012).

- Not suitable for wastewater from flush toilets, unless animal excreta or organic kitchen waste is added (Mang & Li, 2010).
- Not suitable if chemicals, plastics, metal or any other inorganic materials is disposed of in the toilets (Mang & Li, 2010).

2.3.3.6 Minimal safety requirements if no sewage treatment

If the health-care establishment is unable to afford and manage any sewage treatment, the following measures should be implemented to minimize the health risks (Prüss et al., 1999):

- Patients with enteric diseases should be isolated in wards where their excreta can be collected in buckets for chemical disinfection.
- No chemicals or pharmaceuticals should be discharged into the sewer.
- Sludges from hospital cesspools should be dehydrated on natural drying beds and disinfected chemically (e.g. with sodium hypochlorite, chlorine gas, or preferably chlorine dioxide).
- Sewage from health-care establishments should never be used for agricultural or aquacultural purposes.
- Hospital sewage should not be discharged into natural water bodies that are used to irrigate crops, to produce drinking water, or for recreational purposes.

An acceptable solution would be natural filtration through porous soils, though this must take place outside the catchment area of aquifers used for drinking-water (Prüss et al., 1999).

2.3.4 Effluent disposal systems

2.3.4.1 Sub-surface effluent disposal

Subsurface wastewater infiltration systems are the most commonly used systems for the treatment and dispersal of onsite wastewater and need to be located in permeable, unsaturated natural soil or imported fill material so wastewater can infiltrate and percolate through the underlying soil to the groundwater (USEPA, 2002). As wastewater infiltrates and percolates through the soil, it is treated through a variety of physical, chemical, and biochemical processes and reactions (USEPA, 2002). Different designs and system configurations are used, but all incorporate soil infiltrative surfaces that are located in buried excavations and the mechanisms of treatment and dispersal are similar (USEPA, 2002). Research undertaken on the long-term infiltration rates for septic tank effluent has produced the guidelines shown in Table 2.4.

Table 2.4 – Recommended infiltration capacities for different soil types (USEPA, 1980)

Soil type	**Description**	**Infiltration rate (litres/m^2/day)**
Fissured	Variable	Highly variable
Gravel, coarse and medium sand	Moist soil will not stick together	50
Fine and loamy sand	Moist soil sticks together but will not form a ball	33
Sandy loam and loam	Moist soil will form a ball but still feels gritty	25

	when rubbed between the fingers	
Loam, porous silt loam	Moist soil forms a ball which easily deforms and feels smooth when rubbed between the fingers	20
Silty clay loam and clay loam	Moist soil forms a strong ball which smears when rubbed but does not go shiny	10
Clay	Moist soil moulds like plasticine and feels very sticky when wet	<10

a) Soak pit / soakaway

A soak pit is a large hole in the ground from where the effluent can infiltrate into the surrounding soil (Scott, 2012). It relies almost completely on sidewall infiltration (USEPA, 2002; Scott, 2012).

Basic design considerations: Soak pits are commonly 2 to 5 m in depth and 1 to 2.5 m in diameter; their volume should be larger than the tanks they are connected to (Scott, 2012). The pit can either be lined (porous lining) or filled with large stones (see Figure 2.7), blocks or bricks to support the pit walls and cover (Scott, 2012). The soak pit should be separated from the septic tank by at least 3 m, downhill from the health facility, and at a safe distance of 30m from any drinking water source (Jantsch & Vest, 1999). For calculating the volume of the pit, only the wall surface area below the inlet pipe should be considered (Scott, 2012).

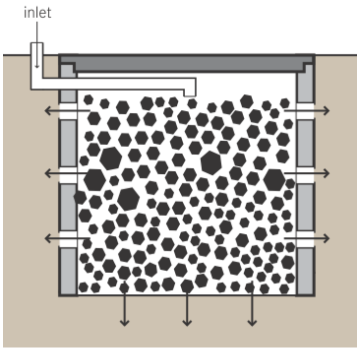

Figure 2.7 – Soak pit filled with stones (Tilley et al., 2008)

Criteria for appropriateness: Soak pits allow the disposal of a limited amount of wastewater from for instance a water point, kitchen or shower (MSF, 2010). Generally, they are only suitable for a single home or small institution (Scott, 2012). They are usually not suitable for high density areas, since an adequate soakaway is often impossible to build (Feachem & Cairncross, 1978).

b) Infiltration trenches

The liquid from a septic tank can also be disposed of in infiltration trenches, which are long lines of porous pipes buried in a trench filled with gravel just below the surface of the ground (Jantsch & Vest, 1999). This provides a higher surface area for the volume of soil excavated (Scott, 2012) and allows the effluent to be widely distributed through a large area of soil and to minimize the risk of overloading in any one place (Feachem & Cairncross, 1978).

Basic design considerations: The trenches should be orientated parallel to the surface contours (see Figure 2.8) in order to reduce linear contour hydraulic loadings and groundwater mounding potential (USEPA, 2002). They are normally between 300 and 600 mm wide and typically about 1m below the bottom of the distribution pipe (Scott, 2012). To calculate the required length of trenches, only the sidewall infiltration area should be included in the calculations (Scott, 2012). The size of the pipe depends on the quantity of effluent to be disposed of, but in most cases 100 mm diameter is sufficient (USEPA, 2002; Scott, 2012). Distribution boxes are used to divide the wastewater flow among multiple distribution lines (USEPA, 2002). The bottom of the infiltration trenches should be at least 1.5 m (preferably 3 m if connected to a septic tank) above the highest possible water table (MSF, 2010). If the soil layer is very thin or the water table is very close to the surface, the infiltration system can be placed in a mound (Scott, 2012).

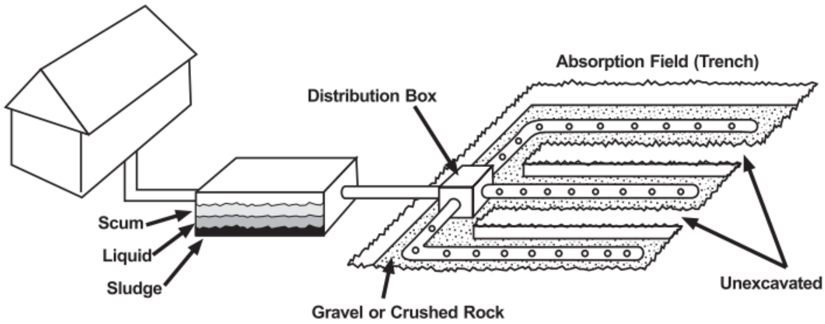

Figure 2.8 – System with infiltration trenches (USEPA, 2002)

Criteria for appropriateness (adapted from Grant & Moodie, 1997):

- Low water table is required.
- Sufficient percolation of the ground (soil permeability) is required.
- Gentle or flat gradient of the ground is required.
- Should be well away from any drinking water sources (see section 2.2.8 for details).

2.3.4.2 Evapotranspiration systems

Evapotranspiration (ET) systems combine the evaporation of water from the soil and the transpiration by the vegetation (MSF, 2010). The effluent (coming from the primary pre-treatment unit) is distributed in open-joint pipes below the ET bed, which comprises a 20-50 cm depth of coarse sand and gravel underlying a 10 cm depth of topsoil, planted with a fast-growing local grass (Feachem & Cairncross, 1978).

Evapotranspiration is a complex phenomenon, but it can be approximated with the following formula (MSF, 2010): *ET rate (mm/day) = 0.8 x ET rate of an open basin.* In the absence of other data, the dimensions of an evapotranspiration area may be calculated on this basis (MSF, 2010): *Effective area (m^2) = volume of wastewater (m^3/day) / ET rate (m/day)*

It is usually preferable to combine evapotranspiration beds with infiltration trenches. Such a system is designed to dispose of effluent by both evapotranspiration and infiltration into the soil (USEPA, 2002).

Criteria for appropriateness:

- Best suited for hot arid climates (USEPA, 2002; MSF, 2010).
- Can be considered if soils are impermeable, e.g. clay or rock (MSF, 2010).
- Can only deal with very limited wastewater volumes (MSF, 2010).
- Very large land area is required, especially if wastewater flow is considerably high.
- Conscientious management is crucial (Feachem & Cairncross, 1978).
- Large capital costs are involved (USEPA, 2002).

2.3.4.3 Disposal into surface water

Effluents from wastewater treatment systems may be discharged into surface water under certain conditions. The treated effluent should meet water quality criteria before it is discharged – specified limits may vary based on the designated use of the water resource or the sensitivity of aquatic ecosystems to eutrophication (USEPA, 2002). The biological self-purification effect of surface waters depends on the climate, weather and on the relative pollution load in the water (Ulrich et al., 2009). The presence of oxygen is a precondition for the self-purification process. Turbulence in surface water increases oxygen intake and therefore reduces the time for recovery after pollution (Ulrich et al., 2009).

2.3.5 Sludge management

2.3.5.1 Desludging of pits and septic tanks

For single pits, it is often advisable to dig another pit for a new latrine, since there are active pathogens present in the sludge, which causes a risk of infection if it is taken out of the pit (Franceys et al., 1992; Scott, 2012). However, in areas where land availability is a constraint, this may not be possible and the pit must be emptied.

Manual emptying: Manual removal of the sludge should be avoided as much as possible from a public health point of view (Franceys et al., 1992), except if the latrine has been closed down for at least two years (MSF, 2012).

Vacuum suction tank: If the sludge is sufficiently wet and liquid, it can be removed by ordinary vacuum tankers (Franceys et al., 1992). Quite often, the sludge first has to be liquefied by adding water and stirring the contents (Scott, 2012). Vacuum tankers are very large and are sometimes unable to reach every destination in dense settlements (Scott, 2012). Smaller, more versatile units have been developed, though they have a very small capacity and the suction pump is generally weak (Scott, 2012). Another approach involves a container, which is connected to the distant tanker by small-diameter vacuum lines, providing the suction necessary to fill the container (Franceys et al., 1992). Once the container is full, the sludge intake needs to be shut off to prevent sludge being carried through the air-line into the vacuum filter and engine (Franceys et al., 1992).

Trash pump: Centrifugal trash pumps are specifically designed to drain liquid sludge that contains solid particles (with diameters up to 30 mm) and can be used to empty septic tanks or latrine pits containing a lot of liquids (MSF, 2010).

Diaphragm pump: Hand-powered diaphragm pumps have proved to be very slow and laborious in emptying pits and have therefore not been widely adopted (Franceys et al., 1992). Motorized diaphragm pumps are designed to drain sludge still containing relatively big solid particles (with diameters up to 60 mm), but the sludge needs to be liquid enough (MSF, 2010). The maximum delivery head and flow are only about half of those of a trash pump with a similar engine, but it can deal with double-sized particles (MSF, 2010).

Submersible grinder pumps: These centrifugal pumps have to be lowered in the sludge and grind potential solid particles (up to a certain size) into small pieces by the cutting blades of the impellor (MSF, 2010). They are more appropriate to empty septic tanks than latrines; and an adapted generator will often be needed for field use (MSF, 2010).

Common pit emptying problems have been identified as the following:

- If the pits are mainly dry, conventional vacuum tankers will not be able to lift dense and viscous sludge or consolidated solid material (Franceys et al., 1992; Thye et al., 2011).
- If the pit is not lined, there is a danger of collapse when solids are removed (Pickford & Shaw, 1997).
- It is often difficult to develop a product that is accessible and yet has the ability to remove sludge effectively (Thye et al., 2011).
- Maintenance of vacuum tankers is often poor; they wear out rapidly and are particularly susceptible to breakdown if preventive maintenance is neglected (Franceys et al., 1992).
- Management and supervision of emptying services is often ineffective (Franceys et al., 1992).

Since all these systems are relatively expensive and require efficient mechanical maintenance, the least sophisticated system should be used wherever possible (Franceys et al., 1992). The technology must be technically and financially sustainable and appropriate to the local situation in order to maximize the benefits to the user and the service provider (Thye et al., 2011). Boot (2007) points out that manually driven mechanical means and specifically designed vacuum tankers represent only a minor contribution to emptying practices around the world; manual emptying (in densely populated areas) and large vacuum tankers are still the most widely employed methods.

2.3.5.2 Sludge treatment and disposal

Consideration must be given to what will happen to the sludge once it has been taken out of the pit or tank. The size of the problem is enormous; only a very small proportion of the faecal sludge in developing countries is disposed of properly, the bulk is discharged indiscriminately into lanes, drainage ditches, open urban space, inland waters or the sea (Scott, 2012). The safest way to dispose of faecal sludge (especially from health-care settings) is by burying it following safe procedures (Adams et al., 2008). Where space is limited and the total volume of sludge to be disposed of is large, this is often not feasible (Scott, 2012). Sludge that has been left undisturbed for over two years is not a hazard to the environment and can safely be spread anywhere convenient (Scott, 2012).

A number of options for sludge treatment and disposal are available:

Wastewater treatment system: If a wastewater treatment system is available, sludge can be disposed of in a preliminary treatment stage (Pickford & Shaw, 1997) or at specially constructed discharge stations (Pickford & Shaw, 1997).

Settling ponds (primary treatment): These are sedimentation or thickening ponds (see Figure 2.9) that create calm conditions in which suspended solids can settle to the bottom; they are usually operated in pairs using a batch system (Scott, 2012).

Figure 2.9 – Sludge settling ponds (Tilley et al., 2008)

Anaerobic digestion (primary treatment): Open deep tanks are used for anaerobic digestion of sludge. Fresh faecal sludge is added to the tank where biochemical processes reduce it and stabilise it (Scott, 2012), ensuring thermal elimination of most pathogens (Prüss et al., 1999).

Sludge drying beds (primary or secondary treatment): Sludge can be deposited onto a shallow tank, which allows drainage and is covered with a layer of sand to form a bed (see Figure 2.10). In favourable conditions, the solids content increases within one week so that it can be lifted by hand or a mechanical shovel (Pickford & Shaw, 1997).

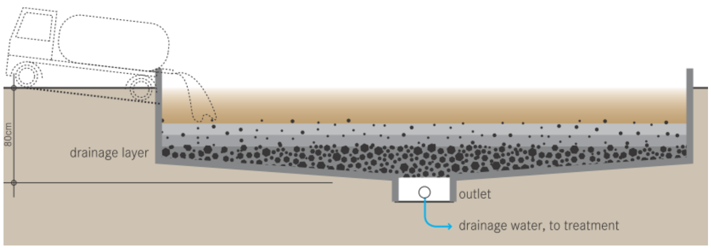

Figure 2.10 – Sludge drying beds (Tilley et al., 2008)

Co-composting with organic waste (secondary treatment): Thick sludge can be added to organic waste for composting (Scott, 2012), and stored for several weeks to finally use as a soil conditioner (Pickford & Shaw, 1997).

Agricultural disposal (disposal option): If the sludge does not contain heavy metals or harmful chemicals, dried sludge can be used as a soil conditioner on agricultural land (Scott, 2012). Sludge from hospitals should not be used for agricultural purposes (Adams et al., 2008).

Landfill or incineration (disposal option): Sludge that is not used as a resource can be disposed of in a sanitary landfill or incinerated together with domestic waste (Scott, 2012). Prüss et al. (1999) recommend that all sludge from health-care establishments should be incinerated.

2.3.6 Disposal of grey water and surface run-off

2.3.6.1 Grey water

Soak pits / infiltration trenches: For situations where on-site disposal is needed, Adams et al. (2008) recommend soak pits or infiltration trenches for grey water. The soak pits or infiltration trenches should not overflow in the surroundings, since it creates insect or rodent breeding sites (Adams et al., 2008). If the wastewater contains soap, oil or grease, they should be equipped with grease traps and checked weekly and cleaned, if needed (MSF, 2010). Dean & Reed (1992) point out that the use of a grease trap or screen will extend the operational life for very little effort. For larger flows, soak pits may not be sufficient to dispose of all grey water.

Other options: Other In-ground systems remain most suitable since a range of options exists that makes them adaptable to almost every site condition (Dean & Reed, 1992). WSPs and ET systems can be considered in certain conditions (Dean & Reed, 1992). Grey water can also be disposed of in a septic tank, or it can be used for watering garden crops or discharged into storm water drains (Jantsch & Vest, 1999). The benefits of pre-treatment using septic tanks are well demonstrated (Dean & Reed, 1992). Unless the BOD of the grey water is very high (500 mg/l or more), anaerobic pre-treatment is not beneficial (Dean & Reed, 1992).

2.3.6.2 Rainwater and surface run-off

Rainwater and surface run-off should be safely disposed of and not carry any contamination from the health-care setting to the outside surrounding environment (Adams et al., 2008). It is also important to drain surface run-off because it prevents the breeding of flies and mosquitoes in stagnant pools and removes floodwater, furthermore poor drainage at public sites can lead to unpleasant and unsanitary conditions (Jantsch & Vest, 1999).

Rainwater and surface run-off can be drained and disposed of separately if the system in place, such as septic tanks, cannot cope with the additional inflow from heavy rains (Grant & Moodie, 1997; Adams et al., 2008). Rain and runoff water that does not contain any contamination can be disposed of by natural drainage without specific treatment (MSF, 2010). Runoff water should never pass through a grease trap as it normally does not contain any oil, grease or fat (MSF, 2010). If natural infiltration does not occur within a few hours, the runoff water can be evacuated directly to surface water sources, but downhill of existing water intake points (MSF, 2010).

2.4 Wastewater disposal in hospitals in developing countries

2.4.1 General situation

Wastewater from healthcare facilities is not much different from liquid waste at other institutions such as schools, factories or government office blocks, where a large number of people come together (Jantsch & Vest, 1999).

Many health-care settings in developing countries are currently far from achieving acceptable levels of environmental health and may have no suitable facilities at all, as a result of lack of funding, skills, technical equipment, appropriate management structures and awareness or adequate institutional support (Jantsch & Vest, 1999; Adams et al., 2008). Particularly rural health facilities are characterised by extremely limited technical and financial resources, difficult logistics and academic isolation (Jantsch & Vest, 1999). Rural health facilities are usually in a less favourable position than urban health facilities, as they often have to rely totally on themselves and have no sewerage system to connect to (Jantsch & Vest, 1999). The Rwandan Minister of Health, Dr Agnes Binagwaho, has acknowledged in January 2012 that the lack of sanitation facilities in hospitals is a big problem, but that it can be solved easily as hospitals can afford to have enough toilets for patients (Musoni, 2012).

Unsafe health-care settings contribute to a significant proportion of some diseases, and the problem is growing worse (Adams et al., 2008). The situation is likely to deteriorate without effective action. Fortunately, the international policy environment (UN Millennium Development Goals) increasingly reflects the problem of health-care associated infections (Adams et al., 2008). The importance of providing adequate sanitation in every health-care establishment, and of handling this issue with special care, should not be neglected (Prüss et al., 1999). To meet the hygienic standards of health facilities, a properly managed system of liquid waste collection, treatment and disposal is of major importance (Jantsch & Vest, 1999). Hospitals and other health centres provide an opportunity to educate visitors and the general population about minimizing disease transmission by providing targeted messages and a “model” safe environment (Adams et al., 2008). Apart from the prevention of health risks, the protection of the environment in general is another reason for the introduction of proper waste management practices (Jantsch & Vest, 1999).

Furthermore, the special needs of hospital patients must to be considered. Since many of the people who use the toilets are sick or disabled, they may find a traditional toilet difficult to use or their disease may cause them to foul the latrine with excreta high in pathogens (Scott, 2012). It is therefore important to construct a variety of toilet designs and aids to help the users (Scott, 2012).

2.4.2 Hazards and risks

Wastewater from health-care establishments is of a similar quality to urban wastewater, but it may contain various potentially hazardous components, such as: microbiological pathogens, hazardous chemicals, pharmaceuticals, radioactive isotopes and other related hazards (Prüss et al., 1999). Additional precautions should be taken to prevent chemicals, certain types of drugs and radioactive substances from being discharged into the wastewater system (Jantsch & Vest, 1999).

If the sewage is discharged to the environment untreated or inadequately treated, it will inevitably pose major health risks (Prüss et al., 1999). Health-care settings are environments with a high prevalence of infectious disease agents; if environmental health is inadequate, patients, staff, carers and neighbours face unacceptable risks of infection (Adams et al., 2008). There is a considerable disease risk for water-, food- or handborne infections, though these can be prevented with an adequate water supply, excreta disposal and hygiene practices (Adams et al., 2008).

There are associated health risks for healthcare personnel, for patients and visitors as well as for the environment and the neighbouring population (Jantsch & Vest, 1999). The discharge of chemical residues into the sewerage system can lead to the pollution of nearby groundwater resources; particularly pharmaceutical residues, some expired drugs, antibiotics, heavy metals and other chemicals represent a high risk if discharged without prior treatment (Jantsch & Vest, 1999).

2.4.3 Saint Francis Hospital, Katete, Zambia

Saint Francis Hospital (SFH) is situated in Katete District in the Eastern Province of Zambia on the main road between Lusaka and Malawi (MSG, 2010). It was founded in 1948 and is administered by a Joint Anglican Catholic Management Board (MSG, 2010). It has progressively grown since then and has become Zambia’s largest church-administered hospital (Cullinane, 2009).

The hospital serves as a general hospital for an immediate population of 240,000 and as one out of two second level referral hospitals for a total population of 1.7 million living in the Eastern province (MSG, 2010; Central Statistical Office, 2011). Patients are referred to SFH for surgery, serious medical paediatric conditions and obstetrics from rural health centres and hospitals (MSG, 2010). The majority of patients are peasant farmers living in traditional rural villages (MSG, 2010). The hospital has 350 beds (SFH, 2012), divided into adult medical (male and female), paediatric, maternity and surgical (male and female – including gynaecology) wards (Cullinane, 2009). Furthermore, there is a labour ward, a basic special baby care unit, two operating theatres and an emergency ward (Cullinane, 2009).

The staff of SFH generally exceeds 319 persons, the majority of whom live within the hospital campus (Cullinane, 2009). It is estimated that the total population of the campus (including all residential buildings) is around 1,600 and is expected to rapidly grow to 1,800 (Cullinane, 2009). It is not known how many people are inside the hospital buildings on any day.

Water is supplied from a number of boreholes. In 2007, the main water tank and adjacent top tanks were rehabilitated, together with the replacement and relocation of the main circulation pumps (Cullinane, 2009). The three PVC ring mains around the hospital supply all hospital departments with water (Cullinane, 2009). It is not known how much water is used for laundry, kitchens, gardening or any other purposes.

In 2007, half of the pit latrines in the high-density housing area were converted to flush toilets; the remaining housing was due to be converted in 2008 (Cullinane, 2009). The wastewater that is produced on the hospital campus is collected by over 100 septic tanks which overflow into soakaway pits (Cullinane, 2009). Neither the volume of wastewater flow nor the wastewater strength is known. The sewerage system comprises of a series of drains discharging to a septic tank; each drain serves one or more buildings (Cullinane, 2009). Maintenance of the system has been non-existent for a number of years due to financial restraints and a lack of suitable equipment (Cullinane, 2009). The hospital does not have any equipment for emptying of the tanks, nor is it available for hire in this area of Zambia (Cullinane, 2009).

2.4.4 Case studies from hospitals and other public institutions

2.4.4.1 Selected results from nine case studies *(Jantsch & Vest, 1999)*

Nine case studies were analysed regarding waste management practice at various healthcare facilities (all located in developing countries). The investigation showed that in the majority of cases they were neither adequate nor sufficient to meet the requirements of hygiene and environmental protection. Out of the nine case studies, only four had a sewage collection system available, and only two had septic tanks installed. None of them had a special waste water treatment system in place.

In terms of waste management administration, the situation proved to be really bad:

- None of them had an existing waste management plan.
- Only one of them was monitoring and recording its waste management activities.
- None of them elaborated the costs of waste management and efforts to reduce them.
- Only one of them had an active information and training of staff in place.
- Only one of them showed protective measures for healthcare facility staff to take place.

2.4.4.2 Nyagatare Hospital, Rwanda *(Rwembeho, 2012)*

The state of the sanitation facilities at Nyagatare Hospital has been reported by patients to be concerning. The poor quality of the toilets, which are completely full, is even noticeable from a distance. Hospital patients stated that there is a considerable risk of contracting an infectious disease while being at the hospital for minor treatment. The hospital management explained that the hospital is overwhelmed by the big population it serves and that they are constructing new toilets and improving the compound.

2.4.4.3 Maracha Hospital, Uganda (Müllegger & Freiberger, 2010)

Maracha Hospital is a small rural hospital (200 patients and 150 employees), where the sanitation infrastructure was rehabilitated in 2001/2002. It consists of single vault urine diverting dry toilets (UDDTs), pit latrines, flush toilets, a drying/composting area with a sludge-drying bed and a vertical-flow constructed wetland system.

The dehydration chambers (where faeces, ash and toilet paper are collected) are emptied by an average of six months and the material is brought to the centralised composting area. It is stored there for 6 months and turned frequently during this time. The compost is then sold to local farmers. The demand for compost is continuously rising since operation began in 2002, since the community around the hospital realized the value of the fertilizer. Sludge from the pit latrines is transported to the sludge drying bed where it is also stored for 6 months and then applied to the hospital's fields. Wastewater from flush toilets, urine from the UDDTs and grey water is collected in a sewer system and pre-treated in filter baskets and then discharged to the constructed wetlands. The treated wastewater is infiltrated outside the hospital's compound without any further use.

Three attendants, who are employed by the hospital, are among other duties responsible for O&M of the sanitation system. They have been trained on-site and in a training course for sanitation personal.

2.4.4.4 Hawassa Referral Hospital, Ethiopia (Dires, 2008)

The hospital has a series of waste stabilization ponds (named oxidation ponds) that are constructed in close proximity to Lake Hawassa. They consist of five stabilization ponds, while the first two are used alternatively (see Figure 2.11 for a photograph). All of the ponds have a similar depth (between 5 and 7 metres), slight differences in length and width have been measured. The ponds are lined at the bottom with a thick plastic layer in order to minimize seepage into the groundwater. An estimated wastewater volume of 47 m^3 per day enters the ponds from the hospital; the hydraulic retention time in the ponds is approximately 42 days. The treated effluent of the ponds is then directly discharged into the lake. Lake Hawassa is used for a variety of purposes like fishing, recreation, swimming and cultivation of vegetables.

Despite a fairly god removal efficiency of faecal and total coliforms, the effluent did not meet the standard level. Neither did COD, BOD_5, nitrogen, ammonium, phosphorus and phosphate meet the permissible level in the effluent. This may be due to the wastewater composition, as it contains various compounds like pharmaceuticals and disinfectants, which may affect the bacterial activity and therefore reduce the removal effectiveness. Another factor for the insufficient removal rate may be the design of the ponds, especially the depth: All the ponds are between 5 and 7 metres deep which means that none of them serve as facultative or polishing ponds. Furthermore, the ambient air temperature around the ponds might reduce the removal efficiency of the stabilization ponds.

Figure 2.11 – WSPs at Hawassa Referral Hospital (Dires, 2008)

The study showed that the water quality of Lake Hawassa may be affected by the release of wastewater from different sources, which is the main threat for not only the lake's aquatic diversity, but also human health around the lake.

2.4.4.5 Kalungu Girls Secondary School, Uganda (Müllegger & Freiberger, 2010)

The school's sanitation infrastructure has been improved in 2003 and gained national and international reputation for its innovative sanitation concept. The implemented system consists of urine-diverting dry toilets, a drying/composting area and a horizontal sub-surface flow constructed wetland (for grey water and black water).

Teachers and students were trained in principles and proper operation of the system and students are fully involved in O&M activities, while the teachers supervise the work. Agricultural products, which are fertilized with urine and dried faecal material, are consumed at the school itself. The school introduced an admission fee for visiting delegations, which is used to maintain the sanitation system.

2.4.4.6 Aravind Eye Hospital, Pondicherry, India (CSE, n.d. and Ulrich et al., 2009)

The hospital has the capacity to treat 750 in-patients and 900 out-patients; 300 paramedical staff is housed in 26 residential quarters. Due to the water scarcity in the region, a wastewater treatment solution that permits the reuse of treated water has been chosen.

Approximately 307 m^3 of domestic wastewater from toilets, bathrooms are treated each day. The grey and black water first enter two separate settlement chambers. The settlement chamber for the black water treatment is integrated with the anaerobic baffled reactors where the wastewater undergoes a secondary anaerobic treatment. The black and the grey water effluent are then collectively passed through an anaerobic filter and then through a series of horizontal planted gravel filters (constructed wetlands). The final treatment consists of polishing ponds where the water is stored for further reuse.

The effluent irrigates a lush green garden area with 300 trees and 4,200 m^2 of lawns within the hospital premises. Through reuse of treated wastewater, 100,000 m^3 of freshwater are saved annually.

2.4.4.7 Hospital at Dhulikhel, Nepal *(Laber et al., 1999)*

Due to the lack of functioning wastewater treatment plants, it was decided to implement a two-stage constructed wetland for the newly built hospital. The system was chosen as it fulfils the following criteria: it was not necessary to import materials from outside Nepal; it can be operated without electricity and it has a high removal efficiency (BOD_5, COD, TSS, NH_4-N and bacteria). The system consists of a three-chambered settlement tank followed by a horizontal subsurface flow bed and a vertical flow bed. Both flow beds are fed intermittently with a specially constructed mechanical feeding unit that works without electricity. The sludge from the settlement tank is dried in a sludge drying bed.

In order to treat the wastewater for the small hospital (40 beds, 10 staff members), a relatively large area was required: 140 m^2 for the horizontal bed and 120 m^2 for the vertical bed.

2.4.4.8 Hospitals in Ho Chi Minh City, Vietnam *(Vietnamnet, 2011)*

The wastewater treatment of HCM City Oncology Hospital has degraded seriously and has been going directly into the environment for the last several years. This creates numerous problems in terms of odour and health hazards. The An Binh Hospital built a wastewater treatment system; however it only operated for two years and has stopped working for the last eight years. Every day 500 m^3 of wastewater are discharged directly into the environment without any treatment.

In one district, out of nine hospitals and one healthcare centre, five hospitals still do not have any wastewater treatment systems. The leaders of one hospital stated that there was not enough room to build a wastewater treatment system.

Every day, 17.500 m^3 of medical wastewater is discharged to the environment, 18% of which does not go through any treatment. The water quality of several rivers showed a higher organic pollution level than in previous years. Only nine out of the 29 districts in the city meet the wastewater treatment standards.

2.5 Summary

The relevant design criteria that are needed to select an appropriate wastewater disposal system have been identified; the SHTEFIE approach has served as a tool to consider all relevant aspects.

A range of technical options for wastewater treatment and disposal (including sludge disposal) have been presented, basic design considerations have been discussed and criteria for appropriateness have been found. The technical options that have been identified to be possibly suitable for Saint Francis Hospital are the following:

(1) Simple pit latrines
(2) Pour-flush pit latrines
(3) Flush toilets with septic tanks and soak pits
(4) Flush toilets with Waste Stabilization Ponds
(5) Flush toilets with aerated lagoons

Please see section 5.4 for an assessment of the feasibility of these five technical options for wastewater disposal. The options for sludge removal and disposal could not yet be narrowed down, since the state of the existing septic tanks is not known; this will be described in detail in chapter 5. Grey water should be disposed of in soak pits or infiltration trenches, ideally equipped with grease traps. Rainwater and surface runoff that does not contain any contamination should be disposed of by natural drainage without specific treatment.

Many health-care facilities in developing countries, particularly in rural areas, do not have suitable sanitation facilities and are often poorly maintained. Likewise, the existing sewerage system with septic tanks and soak pits at Saint Francis Hospital has not been properly maintained for a number of years.

Several case studies from other hospitals and schools in similar conditions have been examined. One crucial factor for a successful and functioning wastewater system has been identified to be clear responsibility and commitment for operation and maintenance activities. Furthermore, the system needs to be designed appropriately for local conditions and according to design standards and guidelines.

3 Methodology

This section outlines the methodology chosen by the author to investigate the research questions described in section 1.2. The methodology was devised in the UK prior to departure for field work and was adapted during the stay in Zambia as the fieldwork progressed.

3.1 Research methods and tools

There are basically two types of research – qualitative and quantitative. Despite this fairly clear distinction between two types of research, there is no reason why methods cannot be mixed; qualitative and quantitative research are not mutually exclusive (Scheyvens & Storey, 2003; Silverman, 2010). Almost all fieldwork generates quantitative data, either intentionally as the main methodology or as a secondary technique to supplement and support other research strategies (Scheyvens & Storey, 2003). Most of the data to be collected for this study is predominantly quantitative, while a part of the data is also of a qualitative character.

Observations: Visual assessments are perhaps the simplest way of gathering information and can be used for both quantitative and qualitative data collection (Scheyvens & Storey, 2003). It allows the assessor to record behaviour of people, the physical condition of sanitation infrastructure and the characteristics of the surrounding landscape (Harvey et al., 2002). Care has to be taken not to make sweeping assumptions based on limited observation (Harvey et al., 2002). If observations involve analysis of human behaviour, this may require more subjective assessments of what is actually happening (Scheyvens & Storey, 2003) and they need to be conducted in a comprehensive and systematic manner (Harvey et al., 2002). Observations will be used to gather a substantial part of the data for this study.

Measurements: Measurements can be used to determine quantities such as available area, latrine dimensions, quantity of water available, volume of pits, soil infiltration rates and geographical positions (Harvey et al., 2002). They are likely to require the data collector to have certain skills and experience in using appropriate instruments (Harvey et al., 2002). Various types of measurements will be used to collect data for this study.

Interviews: There are various interview techniques ranging from unstructured, open-ended discussions to more directed and structured interviews with key informants (Harvey et al., 2002).

Unstructured interviews: Unstructured or ‘depth’ interviews are mainly used to acquire qualitative data as they can get beyond surface appearances and permit greater sensitivity to the meaning contexts surround informant utterances, particularly when sensitive topics are studied (Lee, 1993). Lines of questioning can be clarified, enhanced, guided, probed, extended, diverted or revisited in different ways and at the same time answering the interviewee’s questions (Arksey & Knight, 1999; Lee, 1993). When discussing sensitive topics like sanitation practices, open-ended questioning can provide the interviewee with comfort and status in the interview process (Lee, 1993). Unstructured interviews are not intended to be used in this study.

Structured interviews: Structured interviews follow a set pattern in asking questions or bringing topics up for discussion, but are less rigidly constructed than questionnaires (Scheyvens & Storey, 2003). They may include 'closed questions' but will often involve more open-ended questions and can be designed to elicit data on opinions and behaviour as well as on hard facts (Scheyvens & Storey, 2003). They can therefore cross the boundary between quantitative and qualitative techniques. It is important to balance the need to ask the same question to each respondent with the need to allow respondents to roam more freely with their answers (Scheyvens & Storey, 2003). Since lengthy answers to open-ended questions are often difficult to record by hand, it may be easier to tape the conversation, while answers to standard questions can be easily recorded by hand (Scheyvens & Storey, 2003). Structured interviews form a crucial part of this study, while some questions are of a 'closed type' and others will be more open-ended.

Asking sensitive questions: If certain topics are of a sensitive type (such as defecation practices) it may not be easy to present them to the respondents. It must be decided whether or not to describe the topic in detail at the outset (Lee, 1993). The sensitive topic could also emerge gradually over the course of the interview, which, however, raises questions of informed consent (Lee, 1993). If there is no fear on the part of the respondent that the paths of interviewer and interviewee will ever cross again, this can be essential to ensure trust and get the respondent to talk freely (Lee, 1993).

Secondary Data: Collecting secondary data is standard practice for doing fieldwork in developing countries, whether the researcher undertakes primarily quantitative or qualitative data collection (Scheyvens & Storey, 2003). Such data can be critical not just to analyse in its own right but also to supplement or triangulate the primary research data (Scheyvens & Storey, 2003). One needs to be careful with the use of secondary data – just because data is published or official does not mean it is necessarily truthful or valid (Scheyvens & Storey, 2003). Background information can often be collected before departure and en-route, as well as in the affected area itself (Harvey et al., 2002). Data from secondary sources has been used in the literature review and is also used to gather some other data in the main study.

Focusing on relevant data: As the time and the resources for collecting data is usually limited, it is important to focus on the data that is relevant to the outcome of the study. It is crucial to collect enough data to carry out an effective assessment, but not to waste time collecting unnecessary information (Harvey et al., 2002). During data collection it is always wise to keep in mind the central research questions; if the data being sought does not contribute to answering those questions, it should not be collected (Scheyvens & Storey, 2003). Simply collecting more data does not mean that a better research outcome will be achieved; it may mean the opposite (Scheyvens & Storey, 2003).

Suspecting the data: The data which is collected may be seriously flawed, especially in a developing country context (Scheyvens & Storey, 2003). Since bad data will produce bad results, it is important to apply common sense and healthy cynicism when questioning the data collected and their value for analysis (Scheyvens & Storey, 2003).

Triangulation: The basic idea of triangulation is that data are obtained from a wide range of different and multiple sources, using a variety of methods, investigators or theories (Arksey & Knight, 1999). The different types of triangulation are the following (Arksey & Knight, 1999):

- *Methodological triangulation*: using a variety of methods to collect and interpret the data.
- *Data triangulation*: using a research design involving diverse data sources to explore the same phenomenon.
- *Investigator triangulation*: employing different researchers, interviewers or observers.
- *Theoretical triangulation*: approaching the research with diverse perspectives and hypotheses in mind.

Even though triangulation might be time-consuming and difficult, it can increase the confidence in results, strengthen the completeness of a study and enhance the interpretability of the study (Arksey & Knight, 1999). For the purpose of this study, it was possible to make use of methodological triangulation and data triangulation. The required information was therefore collected from as many different data sources as possible, using a variety of data collection methods.

3.2 Data collection

3.2.1 Tools for data collection

In this study, a combination of tools for data collection is used:

- Observations
- Site surveys
- Measurements
- Interviews (structured, but with open-ended questions)
- Secondary data

3.2.2 How to collect which data

In Table 3.1, each type of data is allocated to one or more data collection tool.

Table 3.1 – Data collection tools for different data

Data	Collection tool
Existing facilities and current O&M arrangements:	
Arrangements of current wastewater disposal system	Observations, interviews
Operational status and effectiveness	Observations, interviews
Main challenges of current system	Observations, interviews
Current institutional arrangements for O&M	Interviews
Current financial arrangements for O&M	Interviews
Number of people:	
Number of people in each ward	Interviews
Total number of people in the hospital	Interviews
Expected development of patient and staff numbers	Interviews
Source characterization:	
Type of anal cleansing materials used	Interviews
Disposal of any other solid materials	Interviews
Wastewater flow characteristics (average, minimum and maximum values and variations of flow)	Estimate from water consumption measurement
Wastewater pollutants (TSS, BOD_5, COD, TN, TP, grease as well as chemicals, drugs, acids, alkaline, heavy metals) and disposal of solid materials	Secondary data, interviews
Water consumption:	
Total water consumption per day	Measurements, interviews
Water used for gardening, laundry, kitchens	Interviews, secondary data
Expected total water demand in 10 / 20 years	Interviews
Site conditions:	
Topography	Observations, measurements
Available space	Observations, interviews
Soil: permeability, ease of excavation	Measurements, interviews
Water availability	Interviews
Location of surface water sources	Observations
Level of groundwater table and its seasonal variations	Measurements, interviews
Location and type of groundwater sources	Observations, interviews
Quality of groundwater from boreholes	Measurements
Natural drainage of runoff water	Interviews
Risk of flooding	Interviews
Infrastructure for rainwater runoff	Observations, interviews
Evaluation of surface water sources as receiver site (water quality, flow volume, designated use)	Observations, measurements, interviews
Precipitation pattern	Secondary data
Average air temperature	Secondary data
Main wind direction	Observations
User requirements:	
Need for separation of the sexes and of staff	Interviews
Need for privacy	Interviews
Preferred type of toilet or latrine	Interviews
Preferred position (sitting or squatting)	Interviews
Method of anal cleansing, material used, its disposal	Interviews
Menstruation (material used, its disposal or being	Interviews

washed and reused)	
Max./min. distance from patients to latrine	Interviews
Acceptability of emptying a latrine pit	Interviews
Legal requirements and guidelines:	
Discharge standards for wastewater effluent	Secondary data
Environmental protection regulations	Secondary data
Guidelines for sanitation in healthcare establishments	Secondary data
Institutional aspects:	
Strategic medium- and long-term plans for SFH	Interviews
Responsibilities for O&M of facilities	Interviews
Intended arrangements for O&M, including funding	Interviews
Existence of Waste Management Plan	Interviews
Support of management and staff	Interviews
Availability of resources:	
Availability of financial resources for construction as well as for O&M	Interviews
Availability of building materials and tools	Interviews
Human resources: availability of skilled and experienced local personnel for construction and O&M	Interviews
Cost and design life:	
Cost for land, materials, labour, supervision, operation and maintenance	Interviews
Intended design life of the proposed system	Secondary data, interviews
O&M needs of selected technical options:	
Skills required for O&M	Secondary data
Financial means required for O&M	Secondary data

3.2.3 Measurements

Topographic site survey: Due to inherent inaccuracies of handheld GPS devices, they are considered not to be particularly appropriate for preparing maps of small areas (Reed, 2012). It is therefore intended to carry out chain surveying, where only the most basic instruments such as measuring tape, ranging rods, arrows and an Abney Level are required (a compass might be useful as well). While horizontal lengths (or slope lengths) are measured with a measuring tape, the vertical angles are measured with an Abney Level (Reed, 2012). The vertical difference can be calculated by multiplying the slope length with the sine of the angle.

Water consumption: Since there are no records of water consumption and no water meters installed within SFH, the water consumption of the hospital (and the residential area) had to be measured. This was done by measuring the water level difference in the main water reservoir (which supplies water to the whole hospital and most of the residential areas) in a 2-hour period. During this period, all borehole pumps which supply water into the main reservoir were shut off. The measured water level difference (measured with a measuring pole) multiplied by the surface area of the reservoir gives the water consumption in the 2-hour period. This was done four times during the same day (6am-8am; 10am-12pm; 4pm-6pm; 10pm-12am) as it was not possible to do it for longer periods, since this would have negatively affected the water supply to the hospital. On the first measurement day (14/6/12) the total water consumption (hospital and residential areas) was measured, while on the second measurement day (19/6/12) the water consumption of the hospital compound only was measured (the water supply to the residential areas was turned off for all 2-hour measurement periods). The water consumption between the measurement periods was interpolated, and information from the SFH maintenance team about known peaks of water consumption was included in the calculations.

Soil analysis: The soil types as well as recommended infiltration rates of wastewater effluent were determined on the basis of Table 2.4. Soil samples at specific locations were taken and the soil was then analysed without the need for any equipment.

Wastewater flow: Since wastewater flow data are unavailable and it is fairly difficult to accurately measure wastewater flow volumes, estimates will be developed from water consumption records and projections. It is assumed that 85% of the water ends up as wastewater (Kayombo et al., 2005).

Wastewater pollutants: Due to time constraints, it is not possible to determine the BOD_5, COD and other wastewater pollutants. Therefore, figures for residential wastewater will be taken from appropriate literature.

Groundwater level: No open wells exist; the groundwater level was therefore not measured.

Microbiological water quality: The bacteriological quality of groundwater (from boreholes) and of certain surface water sources near the hospital were determined by analysing the water samples on the occurrence of Escherichia coli. This analysis has been carried out by Mr Mtonga of the Microbiology laboratory of SFH in April 2012. Since the author couldn't verify the sampling and the testing, the results need to be analysed with care.

Figure 3.1 – Inspection of ST5 with metal pole. © Mirco Keller.

Survey of septic tanks: The existing septic tanks on the hospital site were first observed from the outside (structural status, cracks etc.) and the size measured. The inspection covers were then removed and the interior was first visually examined (level of sewage, type of floating materials etc.). Subsequently, a metal pole (3 m long, with handle, made at the SFH workshop) was used to determine the solidity and viscosity of the septic tank contents (see Figure 3.1 for a photograph of the inspection process). The percentage of sludge and scum within each septic tank could be roughly estimated in this way.

3.2.4 Interviews

The following table (Table 3.2) lists the full names of all interviewees, their function/position and the date that they were interviewed.

Table 3.2 – Interviewees

Name	Function / position	Date
Ian Parkinson	Former SFH Administrator, *by Email to Jim Oliver*	24/2/10
Rosemary Zimba	Planning and Development Manager of CHAZ, Lusaka	4/6/12
Sandie Simwinga	Programme Officer of CHAZ (Med. Eng. & Infrastr.), Lusaka	4/6/12
Sikwewa Kapembwa	Head of Laboratory, SFH	8/6/12
Simon Chisi	Chief Medical Officer, SFH	8 & 22/6/12
Dennis Milanze	Vicar General of the Diocese (Anglican Church), Chipata	8/6/12
Tryfol Phiri	Midwife teacher at Nursing Training School, SFH	11/6/12
Jeremiah Nyirenda	Head of Pharmacy, SFH	12/6/12
Mary B. Sandongo	Nurse in St. Augustine (male medical ward), SFH	12/6/12
Charity Banda	Nursing Officer, SFH	12/6/12
Josphat Phiri	Kizito (male surgical ward), SFH	12/6/12
Moffat Sakala	St. Monica (female medical ward), SFH	12/6/12
Seb Lungu	Mkasa (female surgical ward), SFH	12/6/12
Mr Msonda	X-Ray Department, SFH	12/6/12
Kennedy Mufuzi	St. Lukes (Outpatients), SFH	12/6/12
Stanley Sakala	Bethlehem (Maternity ward), SFH	12/6/12
Nurse	New Children’s Ward, SFH	12/6/12
Robert Banda	Personnel Officer, SFH	12/6/12
Charles Tembo	EWSC, Katete Office	13/6/12
James Cairns	Former Medical Superintendent of SFH, *by Email*	14/6/12
David Kapole	District Environmental Health Officer, Katete	15/6/12
Kennedy Malama	Provincial Health Office, Chipata	18/6/12
Wamuwi Changani	EWSC, Managing Director, Chipata	18/6/12
Matthew Mwale	Hospital Administrator, SFH	22/6/12

The following table (Table 3.3) shows which information is intended to be obtained from whom.

A detailed interview guide was prepared by the author for all interviews (See Appendix A). The guide was produced in order to have a prepared structure for the interview and to set out aims and desired outcomes of the interview. For each interviewee, only the section of questions that are ticked in the relevant row (see Table 3.3) were asked to this person.

The original statements can be found in the interview notes (Appendix B). Information and statements that are taken from these interviews are referred to (in Chapter 4) with the interviewee’s initial of the first name and the full surname (e.g.: I. Parkinson).

Table 3.3 – Interviews: what information was obtained from whom

	1) Current wastewater disposal system	2) O&M arrange-ments	3) Number of people	4) Water consump-tion	5) Site conditions	6) User require-ments	7) Legal standards & require-ments	8) Strategic plans	9) Support for new system	10) Av-ailability of financial resources	11) Av-ailability and cost of other resources
Ian Parkinson	X	X	X	X	X						
Rosemary ZImba		X					X	X	X	X	X
Sandie Simwinga		X					X	X	X	X	X
Sikwewa Kapembwa	X		X	X		X					
Simon Chisi	X	X	X	X	X	X		X	X	X	X
Dennis Milanze	X	X						X	X	X	
Tryfol Phiri	X		X	X		X					
Jeremiah Nyirenda	X		X	X		X					
Mary B. Sandongo	X		X	X		X					
Charity Banda	X		X	X		X					
Josphat Phiri	X		X	X		X					
Moffat Sakala	X		X	X		X					
Seb Lungu	X		X	X		X					
Mr Msonda	X		X	X		X					
Kennedy Mufuzi	X		X	X		X					
Stanley Sakala	X		X	X		X					
Nurse NCW	X		X	X		X					
Robert Banda	X	X	X	X	X	X					
Charles Tembo					X		X				X
James Cairns	X		X	X	X	X		X			X
David Kapole	X	X			X		X	X	X	X	
Kennedy Malama		X					X	X	X	X	
Wamuwi Changani							X				X
Matthew Mwale	X	X			X			X	X	X	

Visit to Chadiza Hospital: On 21/6/12 the new Chadiza District Hospital was visited by a team of 4 people (Mirco Keller, Jim Oliver, Paul Splint and Sandie Simwinga). The construction of the hospital buildings was nearly finished; the construction of the sewerage system (Waste Stabilization Ponds) still remained to be completed. Information about the wastewater disposal system was obtained by observations as well as from conversations with Bernard Khoza (Public Health Officer) and the Site Manager (Ministry of Public Works).

3.2.5 Final meeting with SFH management

A couple of days before the end of the data collection period (on 22/6/12) a meeting was held (see Appendix G for an agenda of the meeting) to inform the hospital management about the progress of the study, what to expect from its outcome as well as to let them know about a number of urgent initiatives. The list of recommended short-term initiatives included advice on various issues that need to be addressed as soon as possible (see Appendix H for details). It was given to the SFH management (Matthew Mwale and Simon Chisi), Bruno Mwale and Hillam Kalumbi (head of SFH maintenance team) after the meeting had concluded.

3.3 Data analysis

3.3.1 Preparation of a detailed map

On the basis of an already existing map of the area (obtained from Paul Splint), the acquired data from the site survey and information from Google Earth (to verify and triangulate certain locations), a detailed map of SFH and its surrounding was produced. The map includes all relevant hospital buildings with septic tank locations, an approximation of residential buildings, roads and paths, boreholes and handpumps as well as all nearby streams. The location and size of certain objects as well as distances were verified by cross-checking different maps and resources.

3.3.2 Analysis of interviews

All interviews were recorded with a voice recorder. The interviews were not fully transcribed, but the relevant bits of information were written down to be used for analysing later. Since most of the answers describe some external reality (e.g. facts, events) rather than internal experiences (e.g. feelings, meanings), this provided a more straightforward approach for data analysis (Silverman, 2010).

Once all the interviews have been conducted, the validity and reliability of each source needs to be evaluated. It is important to check the accuracy of what respondents have said by other observations in order to provide a triangulation of the data (Silverman, 2010). Since a major part of the data was obtained from interviews, this can include personal opinions and possibly biased statements. It is therefore crucial to be aware of the quality of the data and the credibility of the respondents.

Even though the interviews were fairly structured, as a lot of questions are open-ended, it is important to be aware of irrelevant data that is collected during the interviews. It needs to be carefully evaluated which data is relevant for answering the research questions and any unnecessary information should therefore be ignored.

Relevant bits of information from all interviews were then collected together by topic in order to get an overview of the situation and to be able to cross-check certain information that was given by respondents.

3.3.3 Statistical analysis

Even though most data will be of quantitative nature, no statistical analysis was done on the data. As no large amount of quantitative data was gathered, there was no need for applying statistical methods. Graphs and tables (without statistical analysis) were produced where appropriate. Furthermore, the most valuable and insightful use of quantitative data often comes from fairly basic descriptive statistics (Scheyvens & Storey, 2003).

The main statistical measurements for representing quantitative data are the following (Scheyvens & Storey, 2003): Central tendency (mean, mode and median), frequency distribution, dispersion, cross-tabulation and correlation coefficient. Central tendency (arithmetic mean) was used to determine the average dimensions of the septic tanks as well as to estimate the water consumption in between measurement periods.

3.3.4 Situation assessment

A detailed situation analysis of the existing infrastructure, the current arrangements for O&M and the relevant site conditions was conducted. This includes a population estimate, wastewater flow estimates as well as assessments of the current wastewater disposal system.

3.3.5 General recommendations

Any recommended changes that do not depend on the technical option that is selected, are presented in a separate chapter.

3.3.6 Key design parameters

Based on the data collected, the key design parameters that are needed for the design of any future wastewater disposal system is presented in brief chapter.

3.3.7 Assessment of the feasibility of technical options

The technical options that have been identified in the literature review to be possibly suitable for Saint Francis Hospital were assessed for its appropriateness for the situation, taking into account all data collected. The technical options that are considered are:

- Simple pit latrines
- Pour-flush pit latrines

- Flush toilets with septic tanks and soak pits
- Flush toilets with Waste Stabilization Ponds and disposal into surface water
- Flush toilets with aerated lagoons and disposal into surface water

All these options were assessed according to the design criteria (section 2.2) and the criteria for appropriateness for each option (section 2.3). The advantages and disadvantages of each option were elaborated in detail. Special attention has been paid to O&M needs of the technical option and the capabilities of the institution for carrying them out. The feasibility of each option has been discussed and a conclusion made subsequently.

3.3.8 Specify implications for selected options

The two best technical options were selected and described in more detail, covering a range of selection criteria that has been defined at the beginning of section 5.5. It also includes an outline design as well as the related benefits and challenges and institutional implications such as management and O&M needs.

3.3.9 Provide recommendations

In the last chapter, a set of recommendations for SFH is presented, including a brief summary of all relevant aspects and also a recommended course of action for each of the two options.

4 Results

4.1 Site conditions

4.1.1 Land availability

All hospital buildings are on a 450 acre (1.82 km^2) site which is on leasehold held by the Zambian Anglican Council (J. Cairns). The hospital owns all the land in vicinity to the hospital compound. It was not possible to find out the exact boundaries of the land which is owned by SFH. According to the hospital management (S. Chisi), it may not be a problem to acquire more land from the local chief.

4.1.2 Site description

SFH is located at the Great East Road which is the main road (tarmac) from Lusaka to Chipata (see Figure 4.1 for a map of SFH and the surrounding area). The site is fairly flat; the buildings within the hospital compound (yellow buildings on Figure 4.1) are estimated to be within 1 m level difference. To the north of the hospital there are several small streams flowing into Stream A, which flows towards north-west. To the south-west there are also a number of small streams which flow into Stream B. A dirt road (Chisale Road), starting at SFH, leads towards the north-west.

The hospital buildings (in yellow on Figure 4.1) are enclosed with a wall around all buildings, the main entrance is in the south (at the roundabout). The buildings of the NTS (in green on Figure 4.1) are scattered to the south of the hospital buildings. The low-density residential areas are south and east of the hospital, while the high-density living quarters are west and north-west of SFH (Chisale Road, The Street and Lower Street; see Figure 4.2).

Site A (see Figure 4.1): Site A is located in proximity to the Stream A, but sufficiently far away not to be affected by any floods. It is on a fairly flat ridge (with a small hill in the middle) which slopes towards the north-west with about 2° to 3° incline. It is used for agriculture and is about 150 m away from the closest building. The measured level difference between the hospital level and Site A is between 7 and 10 m; According to Google Earth it is about 15 m. The measured distance along the walking path between the closest point on the roundabout and the closest point of Site A is 753 m. A straight line (measured on the map) between the two same points would be about 660 m.

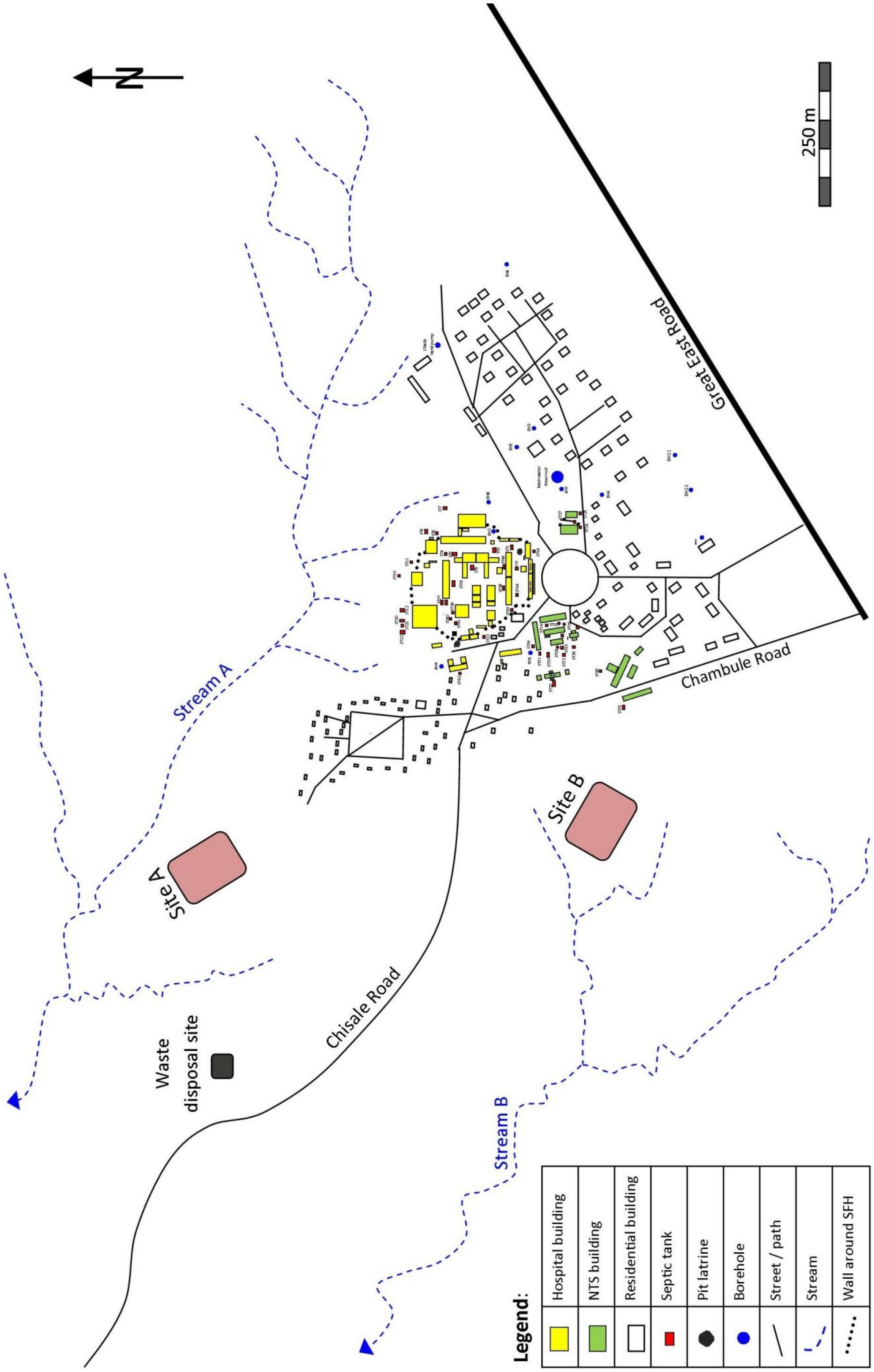

Figure 4.1 – Map of SFH with surroundings © Mirco Keller

Site B (see Figure 4.1): Site B is situated in a fairly flat area (1° to 2° incline towards the north-west) that starts to slope steeper in the north-western end of the site (3° to 4° incline towards the north-west). It is close to a number of springs that form small streams during the rainy season. The site is not used for agriculture and is also about 150 m away from the closest building. The measured level difference between the hospital level and Site B is between 6 and 9 m (8 m with Google Earth). The measured distance along a walking path between the main entrance of the hospital and the closest point of Site B is 439 m. A straight line (measured on the map) between the two same points would be about 390 m.

4.1.3 Soil analysis

Soil samples from excavations near the main entrance of the hospital showed that the top soil consists of loamy sand (infiltration rate of 33 l/m^2/day), while the deeper soil consists of sandy loam (infiltration rate of 25 l/m^2/day). Soil samples from Site A showed the same soil structure as the one above, but there were a number of thin layers of silt loam or clay loam (infiltration rate of 10-20 l/m^2/day) within the deeper soil structure.

4.1.4 Climate

The climate in Katete is fairly mild, with average high temperatures between 22 and 26°C, average low temperatures between 10 and 16°C, and an annual average temperature of 18.1°C (WWO, 2011). Precipitation ranges from 0 mm in the dry season (May to October) up to 162 mm per month at the peak of the rainy season (November to April); total annual rainfall amounts to 699 mm on average (WWO, 2011). The wind direction during the time of data collection was most of the time towards the North.

4.1.5 Groundwater

In the rainy season the groundwater level is very high, the soil can become waterlogged up to the surface, especially in the residential areas (S. Chisi). On the other hand, the groundwater table in the dry season can be as low as 9 metres below the surface (S. Chisi). The groundwater level has not changed significantly over the last 50 years (J. Cairns). There are no open wells or shallow boreholes on the whole hospital compound.

Water is supplied to the hospital, the NTS and all residential areas through a piped water distribution network. The water is extracted from 11 boreholes (see Figure 4.1 and 4.2 for locations), 8 of which were in operation in June 2012. All of the boreholes are about 60 metres deep. Additionally, there is one handpump at the Chada (see Figure 4.1 for location), which is at least 30 m deep and rarely used (as there is now piped water available). Water samples (taken in April 2012 and supervised by Paul Splint) from the borehole pumps (BH2, 3, 6, 7, 9, 11 and 12), the main water reservoir and the handpump were tested for E. Coli. None of the samples were found to be contaminated with E. Coli (0 CFU/ml).

4.1.6 Surface water

Stream A (see Figure 4.1) is seasonal; it dries out in the dry season. The level of the stream can increase in the rainy season, but it never floods as high as the hospital or any residential areas (S. Chisi). Minor floods occur about twice a month during the rainy season, usually for up to 2 hours to less than 10cm in places (J. Cairns). Stream A is joined by a number of other small streams (and also Stream B) and flows towards the north-west where Chisale, a school and a number of other villages are located nearby the river.

A sample (taken in April 2012 and supervised by Paul Splint) from the small stream behind the New Children's Ward (next to ST7, see Figure 4.2) was found to be highly contaminated with E. coli (> 10^5 CFU/ml). Samples taken from Stream A did not show any contamination with E. coli. As the highly polluted stream as well as several effluents from septic tanks flow directly into Stream A, this seems hardly possible. It is very likely that some of the samples got mixed up, leading to these measurement errors.

The local population in Chisale get drinking water from shallow wells and also directly from the stream (S. Chisi). Chisale School and other villages (Jabesi, Alicki and others) have wells and boreholes to obtain drinking water, but the surface water is sometimes also used for drinking purposes, usually towards the end of the dry season (J. Cairns). Reportedly, the population in the villages downstream of SFH are affected by the sewage disposal into the stream and have had to come to the hospital for treatment (S. Sakala). There have been Cholera and Typhoid outbreaks in Chisale and other villages downstream of SFH in the past years/decades, because the local people are using the contaminated water from the stream (M. Mwale; D. Kapole). The danger of contamination increases in the rainy season due to a higher flow rate in the stream (S. Chisi).

4.2 Hospital buildings and toilet facilities

4.2.1 Population estimate

Several people have estimated the total number of people in the hospital; see Table 4.1:

Table 4.1 – Estimates of total number of people in the hospital

	Night	Morning	Afternoon	Average	Minimum	Maximum
S. Chisi	400	800	500	-	-	-
R. Banda	450	-	-	-	800	1,000
J. Cairns	-	-	-	760	-	-

The estimates from Table 4.1 are not considered to be very accurate, since they are not based on reliable data. A second way of estimating the total number of people in the hospital is shown in Table 4.2, where also the numbers of toilets for all buildings are listed.

Table 4.2 – SFH buildings, numbers of people and toilet facilities

Building / ward	Number of people	Patient toilets	Suffi-cient?	Staff toilets	Suffi-cient?	Source
Laboratory	20-30	2		1		S. Kapembwa
NTS	117	?		?		T. Phiri
Pharmacy	30	Use PL1	-	1	No	J. Nyirenda
St. Augustine	85	4	No; Yes	1	-	M.B. Sandongo; C. Banda
St. Monica	65	4	No; Yes	2		M. Sakala; C. Banda
Kizito	75	5	Yes	1	-	J. Phiri
Mkasa	100	4	No	0	No	S. Lungu
Bethlehem	135-185	3	No	1		S. Sakala
St. Lukes	80-160	2	No	1		K. Mufuzi
New Children's Ward	100-200	4		-		C. Banda
Theatre	10	-		-		Estimate
Kitchen	4	-		1		Staff members
Waiters area	50	-		2		Estimate; S. Sakala
Accounts	9	-		0		Staff members
Laundry	4	-		0		Staff members
Registry	20	-		0		Staff members
Physio	5			1		Staff members
Sterilising dept.	2	0		0		Staff members
X-Ray dept.	27	1	No	1	Yes	M. Msonda
Bishop Oliver	10	-		1		Observations
Eye dept.	10	Use PL1		1		Staff members
Administration	10	-		-		Estimate
Dental clinic	5	-		-		Estimate
Total	**973 - 1213**	**29**		**15**		

4.2.2 Toilet facilities

As it can be seen on Table 4.2, there are 29 toilets for patients and 15 toilets for staff; this does not include any toilets in the NTS buildings. All toilets are flush toilets operated with cisterns. About half of them are sit-down toilets, the other half are designed for squatting.

The most common problems with the toilet facilities are blockages (are considered to be the main problem with the toilets according to C. Banda). Blockages have been reported to occur frequently in **Kizito** (J. Phiri), **Mkasa** (S. Lungu), **St. Monica** (M. Sakala), **St. Augustine** (B. M. Sandongo), **Bishop Oliver** (M. Msonda), **St. Lukes** (K. Mufuzi), the **Physio department** and **Bethlehem** (S. Sakala). Occurrence of blockages is reportedly more often during the rainy season, but can also occur during the dry season. The frequency of blockages ranges from about every 3 days in Mkasa (S. Lungu) to about once a month in St. Monica (M. Sakala) to less often in certain wards. The backflow of sewage in St. Monica can sometimes come up to the main ward (M. Sakala); in St. Lukes it has occurred that the sewage flooded up to the main nurses' table (K. Mufuzi). Sewage overflowing to the ground around the septic tanks occurs from time to time, not only in the rainy season (J. Cairns).

Another problem with the toilet facilities is that a number of the cisterns are broken and leaking. Some of the cisterns in Kizito are leaking (J. Phiri). Several cisterns in St. Monica are of very bad quality (M. Sakala). A number of the cisterns in Mkasa as well as the patients' toilet in the X-Ray department are broken (S. Lungu; M. Msonda).

Toilet paper is used for all toilets in all hospital buildings, and is replaced regularly. From time to time, it can run out and it can take a while until it is replaced.

There are no signs in any of the toilets which demonstrate how to use the toilet or what not to dispose of in the toilets.

4.2.3 Pit latrines

There are four pit latrines on the SFH compound (see Figure 4.2 for location). The two that are next to the pharmacy (PL1) are frequently used by patients and relatives. The two other pit latrines (PL2) are probably not used very often. According to J. Nyirenda, the PL1 are flood in the rainy season due to the high water table.

4.2.4 Solid Waste

Solid Waste that is produced in the hospital is disposed in rubbish bins that are placed at certain locations in front of and inside the hospital buildings. It has been reported and observed that in a number of wards, there are no bins available anywhere near the toilets. If any bins exist in the toilet area, it is usually one bin at the entrance to the toilet area.

The bins are emptied frequently. Most of the solid waste is dumped at the waste disposal site (see Figure 4.1 for location), but certain types of wastes (such as needles, sharps etc.) is burnt in the incinerator (see Figure 4.2 for location).

4.3 Source characterization

4.3.1 Water consumption

Please see Appendix F for primary data from the water consumption measurements as well as a graph of the water consumption during 24 hours.

Hospital buildings and NTS: The daily water consumption has been estimated to be at least **217 m^3**, which is based on measurements conducted on Tuesday 19/6/12.

Residential areas: The daily water consumption has been estimated to be at least **270 m^3**, which is based on measurements conducted on Thursday 14/6/12 and Tuesday 19/6/12. According to Dr S. Chisi, the water consumption in residential areas might be higher in the weekends, especially on Saturdays.

Total: The measurements from June 2012 show that the total daily water consumption of SFH is at least **487 m^3**. Paul Splint (Medical Support Group, NL) estimated in March 2012 that the total daily water consumption of the area could be up to **500 m^3** (See Appendix F for more information), which confirms the measurements from June 2012. In 2010, the total water consumption (not at peak time, excluding water used for gardening) was estimated to be around 9 m^3 per hour (I. Parkinson). If this was the average consumption per hour, the daily consumption would come to at least **216 m^3**.

Other information: Water used for gardening accounts for a large proportion of the produced water at the end of the dry season (I. Parkinson), probably two thirds of the staff houses grow a significant proportion of their vegetables (J. Cairns). The water consumption is higher during the hot season (J. Western).

4.3.2 Disposal of chemicals

The chemicals that are discharged into the sinks or toilets are the following:

- Micromatic plus (washing detergent; about 25 kg/week discharged from laundry)
- Deosept/Deosan (disinfection/cleaning solutions, contain chloride, used in most wards)
- JIK (disinfection/cleaning solution, contains bleach, used in St. Lukes)
- Methanol/Ethanol (about 0.25 l/day is discharged from laboratory; S. Kapembwa)
- X-Ray chemicals (Developer and Fixer, used in X-Ray department, about 20 l/month are poured into sink together; M. Msonda)

4.4 User requirements

4.4.1 Distance to toilets

Some of the toilets are a bit far away from the patients, some people have been complaining about the distance and also about the cleanliness of the toilets (S. Chisi).

4.4.2 Need for separation

Patient and staff toilets are usually separated. For historical reasons, patients' toilets often have a squatting pan, while staff toilets have a toilet seat (S. Chisi).

In St. Monica there are not many male people, hence there is no need for a separate toilet for males (C. Banda). Female relatives from St. Augustine are supposed to use the toilets in St. Monica, but this proves to be difficult, especially at night (M. B. Sandongo). There should be a separate toilet for female relatives in St. Augustine, as well as shower (C. Banda). Female relatives from Kizito usually use the toilets in Mkasa, while male relatives from Mkasa use the toilets in Kizito. This can sometimes be difficult, especially at night (J. Phiri). Male relatives in the maternity ward go outside and use the pit latrines, since there are no toilets for men in the maternity ward (S. Sakala).

4.4.3 Types of users

Most patients come from rural areas. Some of them do not know how to flush a toilet, as they have never used one before; this can sometimes prove to be a big problem (J. Phiri). Estimates about the literacy of patients range from only some being illiterate (S. Kapembwa) to a lot being illiterate (J. Phiri) to most patients assumed to be illiterate (S. Lungu; S. Sakala).

4.4.4 Preference of toilet type

Some people from St. Monica prefer to use pit latrines and therefore go outside to use the pit latrines (PL1) behind the building (M. Sakala).

Sit-down toilet would be much more convenient than squatting toilets for patients who have had internal surgery (S. Lungu). Also for patients with fractured legs (who go to the X-Ray), sitting toilets would be much better than squatting toilets (M. Msonda). For pregnant women, sit-down toilets would likewise be more appropriate (S. Sakala). In the experience of James Cairns (at SFH up to 1996), squat toilets were used more efficiently by the majority of patients. However the number of squat toilets was being reduced as they were seen (especially by politicians) as being discriminatory (J. Cairns).

4.4.5 Information of patients and relatives about the use of toilets

Nurses are supposed to orient the patients and relatives about the usage of toilets and what not to dispose in it (S. Chisi; M.B. Sandongo; J. Phiri; M. Sakala; S. Lungu; S. Sakala). Despite this education, some patients continue throwing solids into the toilets, which cause blockages (S. Lungu). Some patients even need to be oriented on how to flush the toilet (M. Sakala). For some patients this is difficult to remember and they forget it (M. B. Sandongo).

Very often, the nurses simply do not have enough time to inform every patient and relative about the use of the toilets (C. Banda; J. Phiri). Outpatients are not informed about the usage of the toilets since there is simply no time to do this (K. Mufuzi).

4.4.6 Materials used if no toilet paper is available

Newspaper (M. B. Sandongo; C. Banda; S. Lungu; J. Cairns), *cloths* (C. Banda; J. Phiri; S. Lungu), *leaves* (C. Banda; J. Cairns); *plastics* (J. Phiri; M. Sakala); *stones* (M. Sakala) and *maize cobs* (C. Banda) are used if no toilet paper is available.

4.4.7 Menstrual hygiene practices

Traditionally, cloths are used for menstrual hygiene, which are washed and reused several times (S. Chisi; C. Banda; M. Sakala; S. Sakala; Nurse NCW). Most women who come to the hospital use cloths for feminine hygiene (T. Phiri). Sanitary cloths might end up in the sewer system (S. Chisi).

Disposable sanitary items (such as pads or tampons) are rarely used by patients at SFH (T. Phiri; M. Sakala). If used they are usually disposed of in bins (T. Phiri; M.B. Sandongo; C.

Banda; J. Phiri; K. Mufuzi) but might also get thrown in the toilet and cause blockages (C. Banda; M. Sakala; S. Lungu). The nurses and midwives usually use disposable sanitary items, the disposal of which has led to problems in the toilets of the hostel (T. Phiri).

4.4.8 Disposal of baby nappies

Cloths (which are reused and not thrown away) are used by most mothers for their babies (C. Banda). Some mothers use disposable baby nappies, but these are usually disposed of in bins and not thrown in the toilet (T. Phiri).

4.4.9 Disposal of other solid materials:

It is probable that items such as dressings, pads, syringes and needles are put into the toilets from time to time (J. Cairns). It occurs that patients in Mkasa throw cloths, bandages and pieces of cotton into the toilet (S. Lungu). In Bethlehem, the disposal of bandages and needles is rare (S. Sakala).

4.5 Existing wastewater disposal system

The current wastewater disposal system of Saint Francis Hospital consists of numerous septic tanks, most of which are connected to a soak pit. The SFH maintenance team on-site does not have a full knowledge of what the current system exactly consists of, where each sewer goes and which septic tank collects wastewater from which buildings. The current as well as the former management of SFH is aware that the sanitary system is certainly a weakness of the hospital (M. Mwale); the system is believed to be inadequate for the volume of wastewater produced (J. Cairns). Also a representative of the Anglican Church (D. Milanze) recognises that the current system of sanitation at SFH is not working.

4.5.1 Sewers

About 10 manholes were inspected. In about three quarter of them, the wastewater was flowing through without any problems or blockages, but in about 25% of the observed manholes, the inlets and outlets were partly or fully blocked with solids that had accumulated or were cracked due to the impact from tree roots.

4.5.2 Septic tanks

There are 46 septic tanks that serve all hospital and NTS buildings (see Figure 4.2 for the exact location of all septic tanks). A small number of these septic tanks could actually be soak pits or some kind of collection pits which are connected to another pit. Due to insufficient knowledge about the current system and difficulties to inspect certain septic tanks, it was not always possible to decide what should be considered as a proper septic tank and what not (See Appendix E for a more detailed list of all septic tanks).

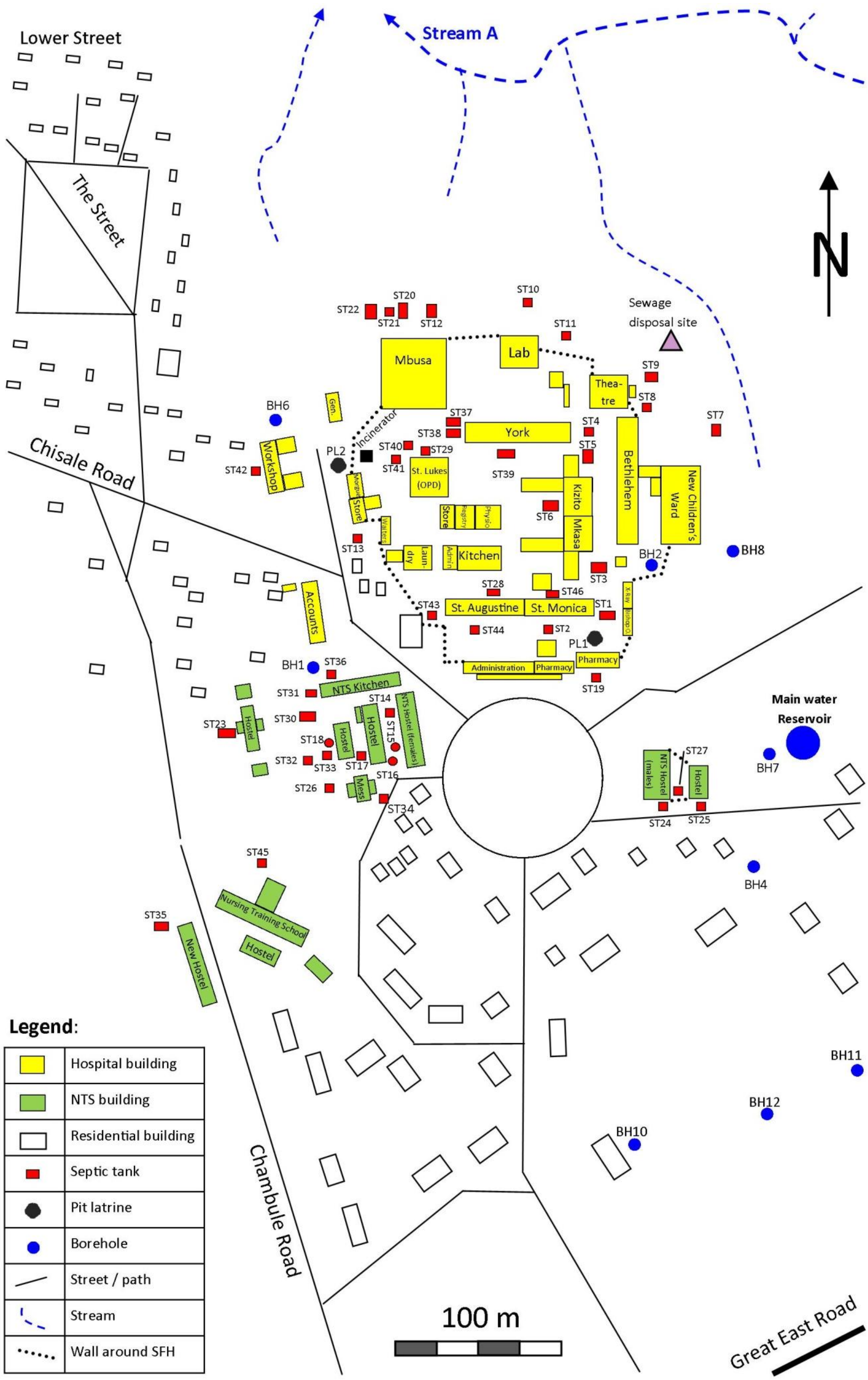

Figure 4.2 – Map of SFH with the location of all septic tanks. © Mirco Keller.

Dimensions: 28 of the 46 septic tanks have been measured in size; the average volume of a septic tank turned out to be 13.8 m^3. The total volume of all measured septic tanks comes to 401 m^3. If all the septic tanks that were not measured in size had average dimensions, the total volume of all 46 septic tanks would be 635 m^3.

Accessibility: Nearly all septic tanks would be accessible for a vacuum tanker, except for ST6.

Existence of soak pit: A number of septic tanks don't have a soak pit at all; the effluent flows into some kind of ditch which eventually ends up in the stream. This is the case for ST7, 8, 9, 10, 11, 12, 20, 21 and 22. ST9 probably collects all the effluents from ST1, 3 and 5.

Proximity to vegetation: A couple of septic tanks are located very close to trees and some of them have cracked and are in a very bad state. The septic tanks concerned are the ones behind the hospital compound (ST10, 12, 20, 21), the ones next to St. Lukes (ST29, 40, 41), one inside the male NTS hostel compound (ST27) and a couple next to the mess (ST34). At the time of inspection, there were hardly any liquids in ST10, as they are probably taken up by the tree next to it.

Use as rubbish pit: ST4 has not been in use for 4 years and has been used as a rubbish pit. Due to the contents, it is impossible to empty ST4. The same problems have been found with ST14 (and to a smaller extent also ST15), which would be very hard to empty.

Newly constructed septic tanks: ST7, 9 and 22 have all been constructed in the last 2 years (2011 or 2012). There are several problems with the construction of those: Wrong shape of the whole tank (ST9 and 22), cover access too small (ST7), level difference between inlet and outlet far too big (ST9 and 22: nearly 1 m), no soak pit existent (ST7, 9 and 22).

Partition wall: Some septic tanks that were inspected were found not to have any partition wall (e.g. ST3, 5 and 6). Apparently they were built without a partition wall to save on construction costs.

Feasibility of emptying: A number of septic tanks that were inspected together with Charles Tembo (EWSC) were found to be feasible to empty with a vacuum tanker. These were ST1, 2, 6, 7, 9, 12, 16, 19 and 22. Several septic tanks that were inspected were found to be impossible to empty with a vacuum tanker. These were ST3, 4 and 5. Furthermore, ST8, 10, 13, 14, 15 and 17 are probably also not feasible to empty.

Various: ST8 and ST10 are nearly empty (only about 10 to 15% of the volume is filled with solids), which is probably due to cracks and leakages. ST3 and its surroundings were flooding frequently, as a result of this the SFH maintenance team constructed a new sewer line which now goes straight through the septic tank into another sewer. The septic tank is therefore not used anymore. ST23 was completely overgrown with plants. Its dimensions were estimated with information from John Western.

4.5.3 Wastewater disposal system in residential areas:

The sanitation system of the residential areas is very similar to the one of the hospital itself; sewers empty into septic tanks (which are sometimes shared amongst more than one house), which eventually dispose of the effluent in soak pits. There are about 100 houses (in 2010) and it is estimated that in total there are about 75 septic tanks in the residential areas, most of which are about 12 m^3 in volume (I. Parkinson). The total volume of all septic tanks is therefore about 900 m^3. In each household there are about six people (I. Parkinson).

4.6 Current O&M arrangements

Maintenance staff: Saint Francis Hospital has a maintenance team, which is responsible for maintaining all infrastructures of the hospital. At the moment, there is no clearly assigned person for maintenance of the sanitation system (M. Mwale). In the past, maintenance of sanitation infrastructure at SFH has been a low priority because the resources were not sufficient (K. Malama).

Achievements in the past: Currently, reactive, rather than preventive maintenance of the sanitation system is carried out (M. Mwale). Attempts to achieve regular maintenance were often unsuccessful because of other urgent needs (J. Cairns).

Budget: The budget for maintenance and emptying of septic tanks amount to 11.025 million ZMK ($2,250) in 2012, 15 million ZMK ($3,060) in 2013 and 16.5 million ZMK ($3,370) in 2014 (St. Francis Hospital Action Plan 2012-2014). These financial figures are only planning figures; it does not mean that the money is actually available at any time (S. Chisi).

Equipment: The SFH maintenance team owns a small pumping device (transported on a trailer, pulled by a tractor) which is used to empty septic tanks or soakaways (J. Cairns). Due to its capacity, this machine is not able to pump any solid matter such as sludge, but can only take out the liquids. The machine is used when a problem arises (such as flooding of the surroundings of a septic tank).

Disposal practice: The sewage which is pumped out of the septic tanks is currently dumped behind the hospital theatre (sewage disposal site, see Figure 4.2 for its location). The tractor pulls the trailer with a tank full of sewage which is then simply dumped into the bush. The sewage then flows more or less directly into the stream, which is less than 50 m away. This practice was observed in mid-June 2012, when the SFH maintenance team emptied a septic tank in the residential area.

Need for training of maintenance staff: Currently at SFH there is not enough technical know-how available for a proper maintenance of the system (D. Kapole). In case of a new system, training of maintenance staff may be required (Rosemary Zimba). On request, the EWSC could offer a training course for the maintenance team of SFH (W. Changani).

4.6.1 EWSC

The EWSC (Eastern Water and Sewerage Company) could do connections of sewers, maintenance of septic tanks as well as maintenance of complete sewerage systems and WSPs (C. Tembo). Skilled and experienced EWSC staff could provide professional support in the design stage of WSPs as well as participate in the O&M activities of WSPs (W. Changani). The EWSC can desludge septic tanks, but if the contents are too solid, it cannot be emptied with the vacuum tanker and the client is advised to scoop out the contents manually; the EWSC does not provide this service (C. Tembo; W. Changani). The hospital management (S. Chisi) as well as the District Health Office (D. Kapole) agree that a partnership with the EWSC might make sense and should be investigated further.

Equipment: EWSC has one vacuum tanker in Chipata (C. Tembo). This tanker (the only vacuum tanker in the whole Eastern Province) is very old and it is likely that it will break down fairly soon. It is not clear what will happen after that (W. Changani).

Disposal practice: If septic tanks in Katete are emptied by the EWSC, the sludge is disposed in the first stage of the WSPs of Katete Girls Secondary Boarding School (C. Tembo).

Costs: According to a quotation from June 2012, the EWSC charges ZMK 400,000 ($80) to empty 5 m^3 of septic tank sludge. A mileage allowance of ZMK 9,000 ($1.8) per km (a round-trip from Chipata is around 200 km, resulting in about $360) also needs to be covered. Additionally, if the EWSC employees have to stay overnight in Katete, a sum of ZMK 810,000 ($160) is charged per night.

4.7 Institutional aspects

The hospital is managed by the Management Committee chaired by the Medical Superintendent (currently Dr Simon Chisi), adopting policies which fall within the guidelines of the MOH (J. Cairns). The Medical Superintendent is responsible to the Provincial Medical Officer of the Eastern Province, which currently is Dr Kennedy Malama (J. Cairns). The Provincial Medical Officer is responsible for ensuring the hospital’s function fall within the government’s guidelines (J. Cairns).

The SFH management would support the idea of having a proper sewerage system (S. Chisi). According to R. Zimba, Sanitation at SFH came out as the number one priority in a meeting with the hospital administration in May 2012.

4.7.1 CHAZ

A representative of CHAZ (R. Zimba) stated that CHAZ is involved in all infrastructure developments in its health facilities, but that improving the sanitation infrastructure at SFH must be a concerted effort from all stakeholders, since it is likely going to be a major program. Sanitation is one core issue in health service provision that has to be taken care of (R. Zimba).

Memorandum of Understanding (MOH and CHAZ, 2011): *Involvement of CHAZ*: "CHAZ shall act as a complementary partner to Government in healthcare delivery. The parties agree that CHAZ at all levels will be fully involved in the planning cycle." *Funding for operational costs*: "The parties agree that the MOH shall calculate funding to the hospitals administered by the MOH and CHAZ on an equity basis (…). There will be a provision in the resource allocation formula to discount for additional funding received by a CHAZ member institution from other sources (…)." *Funding for capital investments*: "The parties agree that CHAZ shall mobilize funding for capital development of CHAZ member institutions. Considerations will be made by the MOH to include church administered health institutions in its capital development plan based on need."

CHAZ partnerships (CHAZ, n. d.): The Memorandum of Understanding guarantees government's support to CHAZ in the form of financial, material, equipment, human resources, etc. The government is the largest single funder to CHAZ funding salaries and operational costs in Church Health Institutions. CHAZ has been integrated in the formal planning cycles of the Ministry at all levels including the community, the district and the provincial levels.

4.7.2 Ministry of Health

Saint Francis Hospital gets a monthly grant from the government; it is expected to prepare a plan how to spend this money (K. Malama). In 2012, SFH received a budget for maintenance and repair of equipment of 172 million ZMK ($35,000), which not only covers sanitation (K. Malama). The central government (MOH) usually has the responsibility for big capital projects (D. Milanze; D. Kapole). Certain projects (especially large infrastructure projects) are undertaken centrally by the MOH and don't necessarily have to be part of the Hospital Action Plan (K. Malama).

Water and sanitation is a priority in the MOH, as well as in the national health strategic plan (K. Malama). The MOH supports all innovations that come from the health institutions, as long as they are evidence-based and the local setup is involved in a participatory manner from the project initiation throughout the project period (K. Malama).

According to the District Health Office (D. Kapole), a team from the MOH came to SFH to do a feasibility study of WSPs, but they have not given any feedback to the District Health Office, nor is it clear when they will be finished with the study or who exactly is responsible for it.

4.8 Legislation

The Environmental Protection and Pollution Control Act (Republic of Zambia, 1999):

Prohibition of water pollution (section 24): "No person may discharge or apply any poisonous, toxic, erotoxic, obnoxious or obstructing matter, radiation or other pollutant or permit any person to dump or discharge such matter or pollutant into the aquatic environment in contravention of water pollution control standards established by the council under this part."

Duty to supply information to Inspectorate (section 25): "Owners or operators of irrigation schemes, sewage systems (…) shall submit to the Inspectorate such information about the quantity and quality of such effluent.

Conditions for acceptance of effluent (section 27): "The local authority operating or supervising a sewage system may impose conditions under which any effluent can be accepted or may prescribe methods of pre-treating the effluent prior to acceptance into the system."

Licence to discharge of effluent (section 30): "No local authority operating a sewage system (…) shall discharge effluent into the aquatic environment without a licence. The Inspectorate may grant a licence for the discharge of effluent under this Part.

Prohibition against disposal of waste (section 50): "No person shall discharge waste so as to cause pollution in the environment." "A person shall not operate a waste disposal site or plant or generate or store hazardous waste without a permit or licence."

The Water Pollution Control (Effluent and Waste Water) Regulations (Republic of Zambia, 1993):

Application for licence to discharge effluent: "A local authority intending to operate a sewage system or owner or operator of any industry or trade which will discharge effluent into the aquatic environment shall apply to the Inspectorate for a licence in Form WP1 set out in the First Schedule and shall pay the appropriate fee set out in the Second Schedule."

Effluent standards: The limit for the BOD of the effluent (mean value over a 24h period) is 50 mg/l for discharge into the aquatic environment. The complete table of standards (limits) with all parameters for effluent and wastewater can be found in the third schedule (Regulation 5(2)) of the Water Pollution Control Regulations (Republic of Zambia, 1993).

4.9 Future plans and population growth

4.9.1 New facilities and renovations of buildings

Mbusa building: Renovation was going on in June 2012; a new OPD (Outpatients Department) with up to 60 beds should be finished in September 2012 (S. Chisi).

York building: This building is currently not in use. Plans for a new Gynaecology, Eye ward and Palliative care unit in York were being drawn in June 2012. The renovated building should be finished by end of 2013 (S. Chisi) with a capacity of up to 60 beds (J. Cairns).

Nursing Training School (NTS): The classroom as well as the residential areas are planned to be expanded; the number of students may double, from currently about 100 students to 200 students (D. Kapole). As there are plans to convert the enrolled nursery into a registered midwifery, this also calls for expansion (K. Malama).

Intensive care unit: There are plans for a new intensive care unit with less than 10 beds, to be implemented within 1 or 2 years (D. Kapole).

Emergency department: Saint Francis Hospital might want a proper emergency department in the future (K. Malama).

Training and conference centre: There is a possibility of a new complex of houses (training and conference facilities) which could accommodate 40 people. Preferably it would be located behind the residential areas on the roadside (S. Chisi).

Eye Hospital: In the long term, there is a possibility of a new, fully-fledged eye hospital, which could treat a maximum of 80 patients. This could be implemented within 10 years (S. Chisi).

Residential areas: The residential areas outside the hospital are growing, more staff houses are going to be constructed in the future (S. Chisi, K. Malama).

4.9.2 Growth in population of SFH

With the information from 4.9.1 and assuming one family member per patient (for the new York building and the intensive care unit) and an emergency department for 10 people, the total additional number comes to 370 people. As these developments are all planned to be implemented within 10 years, this figure can be taken as a rough first estimate for the population growth within 10 years.

A more accurate method of calculating the increase in the hospital population is to take into account the population growth rate of the area. Assuming an annual population growth of 2.7% for the Eastern Province of Zambia, as measured by the Central Statistical Office (2011) between 2000 and 2010, results in an additional population of 336 within 10 years (starting with 1,100 people currently).

4.10 Further information for certain technical options

4.10.1 Septic tanks

The EWSC recommends to empty septic tanks regularly, such as every year, in order to avoid solidification of the contents (C. Tembo).

4.10.2 Waste Stabilization Ponds

The maintenance costs of WSPs are much lower than for septic tanks (W. Changani). WSPs have been found to be more cost-effective in the long term than septic tanks, despite the capital costs being quite high (W. Changani). There would be numerous local companies (in Chipata or in Lusaka) who could tender for the construction of Waste Stabilization Ponds (C. Tembo).

For the construction of the WSPs at Chadiza District Hospital (a new district hospital nearby), the expertise came from the MOH in Lusaka (W. Changani). When observing the on-going construction on site, as well as from the information that was obtained from the site manager, it became clear that the construction is being done wrong. Instead of constructing an anaerobic pond as a first stage, it is put as a second stage, after the facultative pond (which should actually be the second pond). The design of the ponds (which is sample design from the MOH) seems to have been used for other Zambian hospitals as well (as was found out by the author with the use of Google Earth). A copy of the design can be found in Appendix I. The WSPs at Chadiza District Hospital had a budget of 1.6 billion ZMK ($320,000), which includes the complete sewerage system (K. Malama).

5 Analysis

5.1 Situation analysis

5.1.1 Site conditions

Area (see 4.1.1 and 4.1.2): Saint Francis Hospital is located in the Eastern Province of Zambia on an elevation of about 1,040 metres above sea level (see Figure 4.1 for a map). It is situated on a large site (1.82 km^2) which is on leasehold by the Zambian Anglican Council. It is not known where the boundaries of this area are exactly. According to the SFH management, it should not be a problem to acquire more land from the local chief, if needed.

Soil (see 4.1.3): Soil samples have shown that the top soil consists of loamy sand, while the deeper soil mainly consists of sandy loam. At one location there were a number of thin layers of silt loam or clay loam within the deeper soil structure. It is therefore assumed that the majority of the deeper soil (up to 2 m depth) consists of sandy loam.

Groundwater (see 4.1.5): Several local staff members have reported the groundwater level to be very high during the rainy season; the soil at certain points (especially in the residential areas) is said to become waterlogged up to the surface for short periods of time. In the dry season the level has been reported to drop to about 9 metres below the surface.

Climate (see 4.1.4): The average annual air temperature in Katete is 18.1°C. Average low temperatures range from 10 to 16°C, while average high temperatures are between 22 and 26°C. Total annual rainfall amounts to 699 mm on average which distributed over 91 days of rainfall on average.

Wind (see 4.1.4): The direction of the wind during the data collection has been observed to be coming from the South during most of the time.

5.1.2 Population

The total number of people (patients, relatives and staff) within the hospital buildings (including NTS) at any time during the day has been estimated in two different ways (see 4.2.1):

- Several SFH staffs have estimated it to be between 760 and 1,000 people.
- Determining the number of people in each building separately (by interviews with staff members) and adding these numbers up resulted in a slightly higher number of 973 to 1,213 people.

The second way of calculating the number of people is considered to be more accurate, for planning purposes a figure of 1,100 people has therefore been assumed.

5.1.3 Water supply

Groundwater is extracted from 11 boreholes on-site (see Figure 4.1 and 4.2 for locations), 8 of which were in operation during the time of data collection. All of the boreholes are around 60 metres deep. The water from most boreholes is pumped into the main water reservoir (capacity of 463 m^3) from where it is pumped into two top tanks (capacity of 18 m^3) and then into the piped network that supplies the whole hospital, the NTS and most of the residential areas. Two borehole pumps (BH6 and BH9) were supplying directly to the surrounding residential areas without pumping into the main water reservoir. There is one handpump on-site (see Figure 4.1 for its location) which is estimated to be at least 30 m deep and is rarely used due to the piped water supply. There are no shallow wells or boreholes on-site.

The water consumption (see 4.3.1) of the hospital compound has been measured to be approximately 217 m^3 per day. With a current population of 1,100 people, this results in a water consumption per capita of nearly 200 litres per day. This is a very high figure for a rural hospital in sub-Saharan Africa, but is considered to be correct due to leakages, wastages and water used for gardening. The consumption of the whole area (including all residential areas) has been measured to be approximately 487 m^3 per day. According to a staff member of the SFH maintenance team, the water consumption might be evenhigher in the hot season.

The quality of the water from seven boreholes, the main reservoir and from the handpump has been tested during April 2012 (see 4.1.5) and has shown no contamination with E. coli. This shows that there was no contamination of the groundwater with faecal matter. It is assumed that this is very unlikely, since all the boreholes are around 60 m deep and the 30 m deep handpump is hardly ever used. A possible risk for water contamination that has to be considered is the leakage of wastewater from old sewers into leaking water pipes in the ground.

5.1.4 Pit latrines

There are 4 pit latrines on site (see Figure 4.2 for location). The two pit latrines which are inside the hospital premises (PL1, see Figure 5.1) are frequently used. Staff from certain wards (especially from St. Monica) has reported that some patients and relatives prefer to use these pit latrines instead of the flush toilet inside the ward (see 4.4.4). The other two pit latrines (PL2, next to the mortuary) are not used by many people.

Figure 5.1 – PL1. © Mirco Keller.

5.1.5 Toilet cubicles

There are about 29 toilet cubicles for patients and 15 toilet cubicles for staff within the hospital, which excludes the NTS (see Table 4.2). All of these toilets are flush toilets with either a seat or a squatting plate for defecation. 44 toilets for 983 people (1,100 minus 117 from the NTS) results in a ratio of 22.3 users per toilet, which is close to the recommended figure of 20 users per toilet for inpatient settings (see 2.2.4.2) and therefore acceptable. In several wards, the number of toilets has been reported by staff members to be insufficient, but it is typically a matter of only 1 or 2 additional toilets per ward.

A bigger problem seems to be the availability of toilets for relatives of the opposite sex (since the main wards are separated between males and females and the toilets are only for the gender of the patients in that ward). It has been reported by staff that it can prove to be difficult for some relatives to use the toilets in another ward, especially at night.

For a number of people such as patients who had internal surgery (surgical wards), patients with fractured legs (X-Ray department) and pregnant women (maternity ward), toilets with seats would be much more convenient than squatting toilets, according to nursing staff. These types of toilet are not always available for the mentioned groups of patients in the relevant ward.

5.1.6 Sewerage system

As the sewers are below the ground and the maintenance team has a very limited knowledge about the existing sewers, it was not possible to get a lot of information about the sewerage system. Several manholes were inspected (see 4.5.1), most of which were looking okay (the wastewater was flowing without problems), but a number of them (about 25%) were either blocked with solids that accumulated or cracked due to tree roots.

5.1.7 Wastewater disposal system

The wastewater from the toilets, sinks and showers are disposed of in about 46 septic tanks on-site (see 4.5.2 and Figure 4.2 for locations), the average volume of a tank is 13.8 m^3 (see 4.5.2). Most of the septic tanks have an adjoining soak pit (see Figure 5.2 for a photograph of ST6), which receives the effluent from the septic tanks as well as (in some cases) grey water directly from sinks and showers. About 9 septic tanks do not have any soak pit, but discharge their effluent directly into the environment.

Figure 5.2 – Septic tank (ST6) with soak pit in the background. © Mirco Keller.

Numerous septic tanks are missing a partition wall (see 4.5.2), making the treatment process less efficient and making a blockage of the system more likely. Three septic tanks that have been constructed in the last 2 years have several other design faults: wrong shape (square instead of rectangular); level difference between inlet and outlet too big (1 m instead of maximum 10 cm); cover access hole too small for emptying. About 9 septic tanks are located very close to big trees, the roots of which have caused cracks and leakages to the septic tanks, sewers and manholes.

Out of 18 septic tanks that were inspected thoroughly (see 4.5.2), nine were found to be impossible to empty with a vacuum tanker (3 of which were not in use), while the 9 others were found to be feasible to empty (1 of which was not in use). These decisions were based on inspections of the nature and solidity of the contents, conducted with an inspection pole. See Figure 5.3 for a photograph of the solidified sludge of ST5. A selection of photographs of several septic tanks can be found in Appendix D.

Figure 5.3 – Solidified sludge of ST5. © Mirco Keller.

Based on the information that was obtained about the septic tanks (see 4.5.2 and Appendix E), the following estimates were developed:

- 90% (41) of the 46 septic tanks are actually septic tanks. The rest are soak pits that were mistaken to be septic tanks.
- 75% (31) of the 41 septic tanks are currently in use. The 10 others are abandoned and are not receiving any wastewater anymore.
- 70% (22) of the 31 septic tanks that are in use are feasible to empty with a vacuum tanker or another appropriate pumping device. The other 9 septic tanks can only be emptied manually (by scooping out the contents), which is not recommended.

The small stream behind ST7 (which flows into Stream A) has been found to be highly contaminated with faecal matter (see Figure 4.1 and Figure 4.2 for locations). Due to the discharge of septic tank effluent into Stream A, it is assumed to be strongly contaminated with faecal matter as well. Stream A flows through numerous villages where people downstream get drinking water from shallow wells and also directly from the stream. Several people link the contamination of Stream A with Cholera and Typhoid outbreaks in these villages in the past years and decades. According to Simon Chisi, the danger of contamination is thought to be higher in the rainy season due to a higher flow rate in the stream (see 4.1.6).

The sanitation system of the residential areas is very similar to the hospital. There are about 75 septic tanks for the approximately 100 houses, which dispose of the effluent in soak pits (normally there is one soak pit per septic tank).

5.1.8 Problems that occur with the wastewater system

According to staff members, blockages of toilets occur frequently in all hospital buildings (except for the New Children's Ward); sometimes leading to dreadful flooding of sewage up to the wards (see 4.2.2). The blockages are believed to be mainly caused by the disposal of solid materials into the toilets. These solid materials consist of materials for anal cleansing when the toilet paper has run out (such as newspaper, cloths, leaves, plastics, stones or maize cobs), sanitary items (such as sanitary pads or menstrual cloths), as well as occasionally dressings, syringes, needles and bandages (see 4.4.6, 4.4.7 and 4.4.9). Furthermore, blockages are reported to occur more often during the rainy season (see 4.2.2), which might be due to the high water table which inhibits the flow of sewage into certain septic tanks.

Most of the patients and relatives are not well informed about the usage of the toilets, even though the nurses are supposed to orient them about it (see 4.4.5). Very often, the nurses do not have enough time to inform every patient and relative about the use of the toilets. Furthermore, the outpatients (most of whom spend a considerable part of their day in the hospital) are not informed at all about the usage of the toilet. There are no signs in any of the toilets to demonstrate how to use it and what not do dispose of in the toilets.

5.1.9 Disposal of chemicals

The majority of the chemicals that are disposed into sinks or toilets are disinfectants and cleaning solutions (which contain chloride or bleach) as well as washing detergents none of which are used in large quantities or pose any serious hazard. However, there are two other chemicals which are of a bigger concern:

Used X-Ray Fixer, 20 litres of which are currently discharged each month into a sink, is a hazardous waste because of its high silver content of typically between 3,000 and 8,000 mg/l, and should never be discharged in any sewerage system (HERC, n.d.). The Zambian water pollution control regulations (Republic of Zambia, 1993) have a limit of 0.1 mg/l of silver for the discharge of any effluent and wastewater into the aquatic environment.

Used X-Ray Developer solutions, 20 litres of which are also currently discharged in the sink each month, even though not being hazardous, should never be disposed to septic tank systems, since the very high pH may cause the septic tank to fail (DOE, n.d.). If the used X-Ray Developer is mixed with the X-Ray Fixer, the combined solution is considered a hazardous waste and cannot be put in any sewerage system (HERC, n.d.).

5.1.10 Solid waste management

The solid waste that is produced in the hospital buildings is collected in numerous waste bins. These bins are emptied frequently, it has been reported by most staffs that it is usually emptied every day. Within the toilet areas of the wards, there are very often insufficient bins available; in most wards there is maximum one bin in this area – it is usually located somewhere near the entrance to the toilet area. There are commonly no bins provided inside the toilet cubicles.

Most of the solid waste is dumped in the rubbish pit (see Figure 4.1 for location). Every few years the rubbish pit that has filled up is covered and a new one is dug. Certain solid waste (such as needles and syringes) is burned in the incinerator within the hospital compound (see Figure 4.2 for location).

5.1.11 Maintenance arrangements for wastewater system

There is a maintenance team at SFH, which is in charge of maintaining the entire infrastructure in the hospital, which among other things includes maintenance of all buildings, the water supply, the wastewater disposal, the solid waste management and the electricity network. The team is currently led by Hillam Kalumbi, who reports to the SFH management. The maintenance team has limited personnel and resources and has to deal with a lot of different issues, and sanitation is currently not their top priority. Within the maintenance team, there is no clearly assigned person for maintenance of the sanitation system, but one or two people have a better knowledge about the septic tanks and sewers than others and therefore carry out most of these tasks.

The maintenance team carries out reactive maintenance (such as dealing with toilet blockages, flooding or overflowing of septic tanks and soak pits), but not any preventive maintenance. There is no plan for any upcoming maintenance tasks to be done, nor is it known exactly how or when each septic tank has been maintained or emptied last.

There is very little know-how available about the current system and how it is supposed to work. Most of the maintenance team are not even aware that the sludge of a septic tank should be emptied regularly, instead of only pumping out the liquid parts or emptying the soak pit. The current know-how about the maintenance of the system is very limited and considered to be insufficient in order to provide a reliable maintenance regime.

No appropriate equipment for maintaining the septic tanks at SFH is available. The low-capacity pump that is available is only able to pump the liquids and is therefore inappropriate for pumping septic tank sludge.

5.1.12 Institutional aspects

The hospital is partly funded by the Zambian Government (MOH) but also receives funding from the Anglican and Catholic Churches as well as from overseas support groups such as MSG (Medical Support Group, NL) or HATW (Hands around the World, UK) (SFH, 2012). According to the MoU between MOH and CHAZ (2011), which is confirmed on the website of CHAZ (n.d.), the MOH is responsible for the funding of operational costs, while CHAZ should mobilize funding for capital developments. On the other hand, representatives of the Church, the MOH District Office and MOH Provincial Office have stated that the MOH usually has the responsibility for big capital projects.

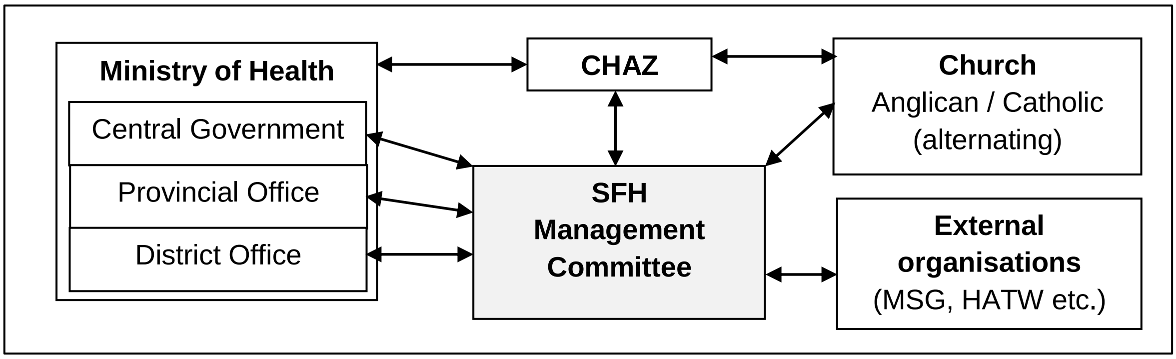

Figure 5.4 – Stakeholders involved in the management of SFH

The hospital is managed by the SFH Management Committee, which is chaired by the Medical Superintendent (currently Dr Simon Chisi), adopting policies which fall within the guidelines of the MOH (see 4.7). The Medical Superintendent reports to the MOH Provincial Office (currently Dr Kennedy Malama) in Chipata. A representative of the District Health Office told the author that the Central Government (MOH) came to SFH in 2012 to conduct a feasibility study of WSPs, but there has not been any feedback and it is not clear who exactly is in charge.

The SFH management acknowledges that sanitation (especially the maintenance) is a weakness of SFH and has never been a priority up to now because of scarce financial resources and other, seemingly more urgent needs. The current budget for maintenance of the sanitation system is very low, which is not even guaranteed to be available at any time, since it is only a planning figure.

The Zambian law prohibits any pollution of the aquatic environment in contravention of water pollution control standards (see 4.8). Disposing of sewage effluent into the aquatic environment requires a licence, granted by the Environmental Inspectorate (see 4.8). It is believed that the Inspectorate is not aware of the current sanitary situation at SFH. Furthermore, it is against the law to dispose any waste (including sludge) so as to cause pollution in the environment (see 4.8). This has also been confirmed by the Managing Director of the EWSC.

All stakeholders that are involved acknowledge that the wastewater disposal system of SFH is in a bad state and all of them would support an improved system (see 4.7). The MOH stated that they support all such innovations, as long as they are evidence-based and participatory throughout the whole project period. Due to the numerous stakeholders involved, it is believed that an improvement of the sanitation infrastructure needs to be a concerted effort from all stakeholders.

5.2 Common areas in need of improvement

5.2.1 Prioritizing sanitation

In the past, sanitation has been a very low priority at SFH. It seems promising that all stakeholders involved acknowledge the bad state of the sanitation system and would support an improved wastewater disposal system. This now needs to be put into action, and a real commitment from all stakeholders to finance and support an improved system is needed.

5.2.2 Sensitisation

The sensitisation of patients and relatives on how to properly use the toilet facilities is vital in order to ensure a correct usage of the system and to reduce the occurrence of blockages. This includes toilet usage (sitting or squatting position), flushing (as reported in section 4.4.3), usage of toilet paper (and not any large solids as reported in section 4.4.6), proper handling of sanitary items (either disposal or washing and reuse, see section 4.4.7) and the proper disposal of any other solid materials (see section 4.4.9).

Firstly, the information of new patients and relatives needs to be improved; the nurses need to have sufficient time for informing each of them about the use of the toilets.

A second initiative that is recommended is the provision of signs on the walls or doors of the toilet cubicles. The signs should demonstrate with clearly (as most patients are illiterate) how to flush the toilets and that no solid materials should be flushed down the toilet. The development and painting of such signs has been initiated in June 2012, but it is not known if anybody has led the continuation of this programme.

5.2.3 Toilet cubicles (flush toilets)

Number: Certain wards do not have sufficient numbers of toilet cubicles. In the main wards (which are separated between males and females), there is the specific problem that there are no toilets at all for relatives of the opposite sex. A sufficient number of toilets for both sexes need to be provided in all wards and other buildings, in order to cater for all people who need to use a toilet at any time. It is expected that only about 5 – 10 additional toilet cubicles are required in total.

Type: The toilets need to be appropriate for the requirements of the users; this means providing the right type of toilet (or a mix of different ones) to each group of patients, relatives and staff. The flush toilets need to be appropriate for the users; for certain groups of patients (see 5.1.5) sit-down toilets are much more convenient than squatting toilets, which needs to be taken into account when deciding on the design of the toilets. Furthermore, at least one cubicle per ward should be appropriate for disabled people, providing more space (for users with wheelchairs) and handrails for support. Moreover, in the wards where there are children, some toilets should be specifically designed for the use by children.

Urinals: It is recommended to provide a number of urinals in the male wards (medical and surgical wards) in order to reduce the number of cubicles required as well as to reduce the fouling of cubicles (see 2.3.1.5). Furthermore, it will also reduce the water consumption for flush toilets. In case of a septic system, the collected urine can be disposed into the septic tank or directly into the soak pit.

Repairs: The toilet cisterns that have been reported to be leaking, as well as any broken toilets need to be repaired as soon as possible in order to ensure a trouble-free operation and to minimise water wastages.

5.2.4 Solid waste management

In certain wards, there are an insufficient number of bins near or in the toilet cubicle for disposing of solid materials. It is recommended to provide one bin inside each toilet cubicle and at least one bin near the entrance of the toilet area. All the bins need to be emptied frequently.

5.2.5 Discharge of X-Ray chemicals

The current practice of discharging X-Ray Fixer and X-Ray Developer into a sink needs to be stopped immediately. The X-Ray Fixer is hazardous because of its high silver content and the X-Ray Developer may cause the septic tank to fail because of its high pH. None of them should therefore be disposed into a sink or toilet but need to be managed as follows:

Used X-Ray Fixer should either be disposed of off-site as a hazardous waste or treated in a silver recovery unit (HERC, n.d.). If there is an off-site recovery unit available, this is considered to be significantly less burdensome than sending it to a disposal site (HERC, n.d.). An on-site silver recovery unit is often the most expensive alternative, as the capital costs of a unit are more than $200 and the annual O&M costs between $100 and 400$ (HERC, n.d.). Operating a silver recovery unit only makes economic and practical sense if at least 2-3 gallons (7.6 – 11.4 litres) per week are used (DOE, n.d.) - which is not the case at SFH. It is therefore recommended to look for an off-site recovery unit or a hazardous waste disposal site.

The used X-Ray Developer should never be discharged to a septic system (DOE, n.d.). It is recommended to dispose it to a sewerage system with wastewater treatment, though restrictions or guidance by the authority need to be adhered to (HERC, n.d.).

5.3 Key design parameters

5.3.1 Population

Assuming an annual population growth of 2.7% (see 4.9.2) results in the following population figures (number of people within the hospital and the NTS) for the coming 20 years. Table 5.1 shows the anticipated population as well as the design figure that has been assumed.

Table 5.1 – Population figures

Year:	**2012**	**2022**	**2032**
Population (design figure in brackets):	1,100	1,436 (1,500)	1,874 (1,900)

5.3.2 Wastewater quantity

Assuming that 85% of the water consumed (see section 4.3.1) ends up as wastewater and that the increase in water consumption is proportional to the population growth, the following figures (see Table 5.2) were obtained:

Table 5.2 – Water and wastewater quantity

Year:	**2012**	**2022**	**2032**
Water consumption (only hospital):	217 m^3/day	283 m^3/day	370 m^3/day
Quantity of wastewater (only hospital):	184 m^3/day	241 m^3/day	314 m^3/day
Water consumption (whole area):	487 m^3/day	636 m^3/day	830 m^3/day
Quantity of wastewater (whole area):	414 m^3/day	540 m^3/day	705 m^3/day

5.3.3 Wastewater strength

The BOD_5 of typical residential untreated wastewater usually ranges from 100 to 400 mg/l (Burks & Minnis, 1994). For the wastewater at SFH, the lowest figure of 100 mg/l has been assumed because of dilution due to the very high water consumption per capita.

5.3.4 Sludge accumulation

The solids accumulation rate per person is assumed to be 0.04 m^3/person/year (see 2.3.3.1 and 2.3.3.2). Table 5.3 shows the calculated total solids accumulation (hospital and NTS) for the coming 20 years.

Table 5.3 – Anticipated sludge accumulation

Year:	**2012**	**2022**	**2032**
Solids accumulation:	44 m^3	60 m^3	76 m^3

5.3.5 Soil property

The majority of the deeper soil (up to 2 m depth) has been identified to consist of sandy loam. The infiltration rate of sandy loam is 25 l/m^2/day (see table 2.4).

5.3.6 Climate

Average annual air temperature: 18.1°C

Total annual rainfall: 699 mm

Wind direction: South

See 5.1.1 for more information on the climate of Katete.

5.4 Assessing the feasibility of options for wastewater disposal

In the literature review, five possibly suitable options for wastewater disposal had been identified (see 2.5). In this section, these five options are going to be assessed for their feasibility and their advantages and disadvantages will be elaborated. Each option will then be discussed and a conclusion about its feasibility will be made.

5.4.1 Simple pit latrines

5.4.1.1 Description (see 2.3.1.1 for more details)

A simple pit latrine consists of a slab over a pit which may be about two metres or more in depth. It can be operated with a slab or a seat so that the excreta fall directly into the pit.

5.4.1.2 Advantages

- Pit latrines are very simple and cheap to build, operate and maintain.
- No water is needed for operation.
- The slab and the shelter can be re-used after a pit is filled up.
- Any solid materials can be disposed in the pit (even infectious material, needles and sharps) provided that the pit is not excavated once it is full.

5.4.1.3 Disadvantages

- Pit latrines are considered to be most appropriate for household use and not for institutions such as hospitals. Also the management and staff of SFH consider pit latrines to be inappropriate for this hospital.
- Pit latrines need to be constructed outside of the hospital buildings, making it impossible to provide the convenience of having toilets inside of the wards.
- The infrastructure that is already in place (flush toilets, sewers, septic tanks, soak pits) will not be used anymore if pit latrines are provided for the whole hospital.
- The high water table (during the rainy season) will make the construction of pit latrines more difficult and costly as they will need to be raised above the ground.
- Pit latrines can cause considerable fly nuisance.

- If a pit latrine is used by many people, it can fill up fairly quickly. Once the contents of a pit have reached 0.5 m below the top, it either needs to be excavated (with appropriate desludging equipment) or filled up with earth and a new pit needs to be dug.

5.4.1.4 Conclusion

Due to the large number of disadvantages (which cannot outweigh the advantages), pit latrines are not considered being feasible on a large scale for SFH. Nevertheless, it is recommended to continue with the operation of the existing 4 pit latrines (PL1 and PL2) and to build a few more. It is suggested to build 6 more pit latrines at 3 locations (PL3, PL4 and PL5, see Figure 5.5), each with one cubicle for males and one for females. This will enable all patients and relatives who prefer to use pit latrines instead of flush toilets to do so. Furthermore, it will allow these people to dispose any solid materials into the pit (assuming the pit is not excavated once it is full). Eventually this will reduce the occurrence of blockages in the flush toilets and sewers.

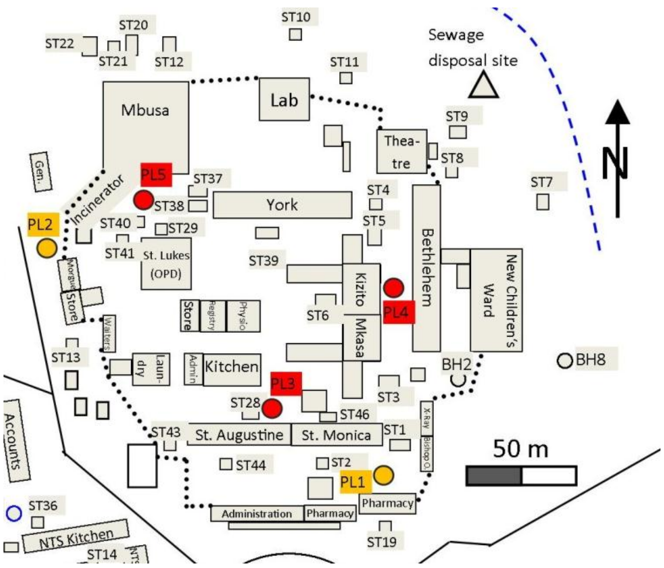

Figure 5.5 – Suggested location of new pit latrines

5.4.2 Pour-flush pit latrines

5.4.2.1 Description *(see 2.3.1.3 for more details)*

A pour-flush pit latrine consists of a pit and a trap which is fitted to a collection pan to provide a water seal. By pouring in sufficient quantities of water, it can be cleared of faeces. The water-seal pan can either be fitted directly into the cover slab or be separated from the pit and connected with a short length of sewer. It is also possible to connect two pits to one water-seal pan by short lengths of sewer that converge at an inspection chamber; the pits are used alternatingly, one can be emptied while the other one is in use.

5.4.2.2 Advantages

- Pour-flush pit latrines are fairly simple and cheap to build, operate and maintain.
- Considerably less water is needed for its operation compared to flush toilets.
- The water seal prevents odours, flies and mosquitos from getting out of the pit.

5.4.2.3 Disadvantages

- Pour-flush latrines are currently not used anywhere on the hospital premises. It would therefore require considerable time and effort to introduce this technology. It is also not known if such a system is socio-culturally acceptable.
- The pits and probably also the toilet buildings will need to be constructed outside of the hospital buildings, making it less convenient for the users.
- It is not possible to dispose any large solids into the pit without causing blockages
- The high water table will necessitate a construction of the pits above ground, making it more difficult and more costly.

5.4.2.4 Conclusion

Due to serious disadvantages, pour-flush pit latrines are not considered to be appropriate for Saint Francis Hospital.

5.4.3 Septic tanks with soak pits

5.4.3.1 Description *(see 2.3.3.1 for more information)*

Flush toilets, sinks and showers are connected to septic tanks by sewers. A septic tank is an underground watertight settling chamber into which the raw sewage is delivered. Septic tanks provide a partial treatment by separation of solids and decomposition by bacteria as well as some peak flow attenuation. The effluents from septic tanks are disposed of by subsurface wastewater infiltration systems (soak pits or infiltration trenches).

5.4.3.2 Advantages

- The flush toilets can be located inside the buildings and provide a convenient system which reduces the occurrence of flies, mosquitoes and odours considerably.
- Most of the infrastructure is already in place, no large financial expenses are therefore required for constructions.
- Can be used regardless of daily wastewater flow rate or strength, provided the septic tanks are designed accordingly.
- Not only the wastewater from the toilets, but also all grey water from sinks and showers can be disposed in the septic tanks.
- If the system is properly designed, operated and maintained, it can provide a safe option of wastewater disposal and public health risks would be reduced considerably.

5.4.3.3 Disadvantages

- Certain capital expenses for the construction, replacement and rehabilitation of septic tanks and soak pits will be required.
- A reliable and ample water supply is essential.
- Blockages are likely to occur if large solid materials are disposed in the toilets.

- The high groundwater table can have a negative effect on the operation of septic tanks.
- Discharge of large quantities of disinfectants or strong chemicals might severely hinder the operation of the septic tanks.
- Appropriate equipment for maintenance (especially a septic tank desludging device) needs to be acquired.
- The sludge needs to be removed periodically; a skilled maintenance team with an appropriate budget and the right equipment is needed.
- If the sludge disposal is not managed properly, a very high public health risk remains.

5.4.3.4 Conclusion

Despite its numerous challenges, a septic tank system is considered to be a feasible option for wastewater disposal. All of the listed disadvantages can be overcome with appropriate initiatives, requiring commitment and sufficient financial means from the SFH management. It will be beneficial for the hospital if they can make use of the existing infrastructure instead of constructing a completely new system that can be very expensive. A system with septic tanks and soak pits is therefore considered to be a feasible option for wastewater disposal at SFH; see section 5.5.2 for a detailed description of the system and its implications.

5.4.4 Waste Stabilization Ponds

5.4.4.1 Description *(see 2.3.3.2 for more information)*

Flush toilets, sinks and showers are connected to a sewerage system, which delivers the sewage into the first pond of a system of Waste Stabilization Ponds. WSPs are artificial lakes which provide treatment through natural processes. The system consists of at least three ponds in series: an anaerobic pond, a facultative pond and at least one maturation pond. The final effluent can be discharged into a river or can be used for the irrigation of crops.

5.4.4.2 Advantages

- The flush toilets can be located inside the buildings and provide a convenient system which reduces the occurrence of flies, mosquitoes and odours considerably.
- A sewerage system can cover the hospital, the NTS and most of the residential area.
- The WSP system is very effective in sunny climates.
- Natural processes provide an effective treatment of the wastewater, not requiring any energy for its operation.
- The final effluent can safely be disposed of in a stream or can be used for agriculture.
- Maintenance of the system is cheap and simple.
- The sludge from any remaining septic tanks can be treated in the same system.

5.4.4.3 Disadvantages

- A large area of land is required.
- The costs for the construction of the system are fairly high.
- If the sewerage system is poorly constructed, the flow of the sewage will be obstructed.
- A routine maintenance of the ponds needs to be ensured; otherwise it may cause a system failure.
- Slight nuisances from odours, mosquitoes and flies are possible.
- Any septic tanks that cannot be connected to the sewerage system (due to the topography) will still need to be operated and maintained properly.

5.4.4.4 Conclusion

Waste Stabilization Ponds can be a feasible option for SFH, provided that the challenges mentioned are overcome. As the availability of land is not a constraint, the main issues will be to ensure sufficient financial resources to cover an appropriate construction of a sewerage system and the ponds as well as to put in place a routine maintenance system. Furthermore, sufficient attention needs to be paid to any remaining septic tanks and the operation and maintenance of them. A system with WSPs is therefore considered to be a feasible option for wastewater disposal at SFH; see section 5.5.3 for a detailed description of the system and its implications.

5.4.5 Aerated lagoons

5.4.5.1 Description *(see 2.3.3.3 for more information)*

Aerated lagoons are a more advanced option of Waste Stabilization Ponds. Oxygen is injected into the wastewater by electrically-powered floating surface aerators, diffusers or submerged air pipes.

5.4.5.2 Advantages

- Less land is required than for WSPs.
- Can be appropriate for climatic conditions which are less favourable for WSPs.

5.4.5.3 Disadvantages

- The wastewater treatment is less effective than WSPs at removing pathogens.
- A stable power supply is required, which is not the case at SFH.
- Substantial financial means for O&M are required.
- The routine maintenance requires semi-skilled operators.

5.4.5.4 Conclusion

As the availability of land is not a constraint and the climatic conditions are ideal for WSPs, the disadvantages clearly outweigh the advantages. Aerated lagoons are therefore considered not to be feasible as a wastewater disposal system for SFH.

5.5 Selecting the best option for wastewater disposal

5.5.1 Selection criteria

The following five selection criteria have been identified in order to select the most appropriate option for wastewater disposal at SFH:

1. Capital costs
2. Expertise required for O&M
3. O&M costs
4. Convenience and reliability
5. Design life

For both options (Option 1 and Option 2), each of these five selection criteria will be described after a general description of the wastewater disposal system.

5.5.2 Option 1: Improving the current system

5.5.2.1 Description

The existing system (flush toilets, septic tanks, soak pits) remains in place and its system components are rehabilitated, replaced or improved where needed. An appropriate desludging device is acquired and a means of sludge disposal is identified.

Septic tanks: Any new constructions of septic tanks should be done on-site, as the author could not identify any Zambian supplier of prefabricated septic tanks (which might have been cheaper and more convenient than in-situ constructions). In order to ensure a correct construction, it is recommended to produce a standardized design (based on the basic design features in 2.3.3.1) for septic tanks that can be used for any new septic tank constructions. As the wastewater flow for each building is not known, the size of each septic tank should be based on the surface area of the building served. Furthermore, the depth of the groundwater table needs to be considered before constructing or repairing any septic tank; the highest water table in the rainy season needs to be lower than the inlet of the septic tank, otherwise blockages are likely to occur.

Soak pits: Likewise, for the construction of new soak pits a standardized design should be produced. In order to calculate the required volume, only the wall surface (below the inlet pipe) should be considered. At locations where the infiltration capacity of a soak pit is insufficient, it might be better to construct infiltration trenches instead of a soak pit (see 2.3.4.1), which would also be beneficial in case of a high water table.

Sewers: About 25% of the sewers and manholes need maintenance, rehabilitation or replacement. For the kitchen and the laundry building, it is recommended to install grease traps (see 2.3.3.1) close to the wastewater source of these two buildings. This will prolong the life of the respective septic tanks. It is of vital importance to ensure regular remove of the grease and solids as well as cleaning of the chamber.

Desludging: The EWSC vacuum tanker is very old and prone to breakdowns, the lack of preventive maintenance often being the cause for major repairs (Tilley et al., 2008). Furthermore, it is fairly expensive to hire: assuming a desludging period of 2 years, annual emptying charges of more than $6,000 (for the hospital and NTS only) have been calculated. It is therefore not recommended to rely on that vacuum tanker for emptying of the septic tanks. Neither is it financially feasible for SFH to buy a vacuum tanker, which costs between $50,000 and $80,000 (Klingel et al., 2002). It is therefore recommended to acquire a 3'' diaphragm pump, which can deal with double-sized particles compared to centrifugal trash pumps (MSF, 2010), would only cost $2,000 - $5,500 (Gongol, 2011) and is also much easier to maintain compared to a vacuum tanker (see 2.3.5.1). There are various manufacturers of diaphragm pumps that can be used for pumping septic tank sludge. One diaphragm pump should be sufficient as an emptying device for all the septic tanks at SFH. The total sludge accumulation per year (only from the hospital and the NTS) has been calculated to increase from currently 44 m^3 to 60 m^3 (in 10 years) to 76 m^3 (in 20 years).

Sludge disposal: The option of disposing the septic tank sludge in the WSPs of Katete Girls Boarding School (about 7 km north-east from SFH, currently managed by the EWSC) is considered not to be feasible due to the insufficient capacity of the ponds (size and number of buildings served has been estimated with Google Earth). It is recommended to construct two sludge settling ponds on-site which can receive the sludge of all septic tanks of the hospital. The ponds can be used alternatingly; the sludge in the one which is not in use is left to dewater and dry and can then be removed and used as a soil conditioner or be buried. Any effluent out of the ponds needs to be disposed of properly through infiltration into the ground. Koné & Strauss (2004) recommend letting the solids accumulate to 50 cm depth and then change to the other pond. The ponds need to be designed based on an assumed pond emptying frequency and on the expected solids accumulation rate (Koné & Strauss, 2004). Considering the calculated annual sludge accumulation (in 10 years) of 60 m^3 and assuming a 6-month cycle, the following sizes are recommended: Each of the two ponds will need to be able to store sludge from 6 months (30 m^3) at a maximal depth of 0.5 m, meaning that an area of 60 m^2 is required for each pond. Two ponds of 10 m length and 6 m width (each) would therefore be sufficient for all the septic tanks in the hospital and the NTS. A more sophisticated option of sludge disposal would be to construct unplanted sludge drying beds (see 2.3.5.2), which would be more efficient, but also more expensive to construct, operate and maintain.

5.5.2.2 Capital costs

Any new constructions and rehabilitations of the existing infrastructure will incur considerable costs. It is expected that not more than 9 new septic tanks and about 10 new soak pits will be required; furthermore, all soak pits need to be replaced every few years. About 25% of the existing sewers will need thorough maintenance or replacement. It is not anticipated that this should prove to be a problem, since the current practice is to regularly build new septic tanks and soak pits anyway, therefore there should not be a shortage of funds for this purpose.

The construction of the sludge settling ponds should be fairly straightforward and cheap, since the required dimensions will be very small. Furthermore, the costs of an appropriate diaphragm pump - $2,000 to $5,500 (Gongol, 2011) - needs to be covered.

Overall, the required total capital costs for this option have been estimated to be less than $50,000, which is more than six times less compared to Option 2.

5.5.2.3 Expertise required for O&M

The maintenance of the system would mainly involve inspections of manholes and septic tanks, dealing with blockages in sewers and toilets, desludging of septic tanks, cleaning of grease traps, repairing broken pipes or septic tanks and managing the sludge settling ponds. The personnel that carry out these tasks need to have a very good technical know-how of the necessary issues as well as a good understanding of the system itself. They need to carry out repairs, plumbing works, the O&M of the diaphragm pump, manage the sludge settling ponds and be able to carry out preventive maintenance according to a schedule.

The SFH maintenance team currently has a very poor understanding of the current system and its operation and maintenance. There is therefore a strong need for developing the skills and the expertise of the maintenance personnel. A professional training of the relevant staff is strongly recommended in order to develop the understanding of the system, its operation and its maintenance. Such a training course could be offered by the EWSC, but it is expected that they cannot provide any guidance on diaphragm pumps.

Even though it is not known how much an appropriate training course would cost, it is certain that the benefit and the cost-savings of a better maintained system are far bigger than the cost of the course itself.

5.5.2.4 O&M costs

Expenditures for operation and maintenance of the system will mainly consist of labour costs, energy (fuel) costs, materials and tools. It is not possible to estimate the annual O&M costs at this stage. However, they annual O&M costs of a diaphragm pump are assumed to be considerably cheaper than if the EWSC vacuum tanker was hired for desludging.

5.5.2.5 Convenience and reliability

The convenience of the system is very good. Flush toilets can be located inside the buildings close to the patients and the septic tanks are not as close as to create any nuisance. Any sources of wastewater (also sinks and showers) can be connected to the system and dispose of it safely.

If the system is wrongly constructed or if the maintenance is not carried out correctly, there is a big risk of system failures occurring. This can include blockages of sewers and toilets as well as flooding of areas in proximity to the septic tanks and soak pits. If the system is working properly and regular inspections and maintenance tasks are carried out, the system should provide a reliable means of safe wastewater disposal without major public health risks.

5.5.2.6 Design life

Septic tanks have a long service life (Tilley et al., 2008); a properly constructed and maintained septic tank can last for 20 years or more (USAID, n.d.). A well-sized soak pit should last between 3 and 5 years without maintenance; to extend its life, care should be taken to ensure that the effluent has been clarified and/or filtered well to prevent excessive build-up of solids (Tilley et al., 2008).

5.5.3 Option 2: Waste Stabilization Ponds

5.5.3.1 Description

A new sewerage system collects all the wastewater and disposes it into the first pond of a series of Waste Stabilization Ponds (WSPs). The WSP system consists of one anaerobic pond (AP), one facultative pond (FP) and at least two maturation ponds (MP). The final effluent from the last MP is discharged into a stream. Two sites have been identified for a possible location of the WSPs. After a brief description of each site and its implications, the design of the WSPs will be explained in detail.

As inevitably there will be a number of septic tanks that cannot be connected to the sewerage system, it makes sense to treat the sludge together with the wastewater in the ponds. Additional to the WSPs, two small Faecal Sludge Ponds (FSPs) are recommended to be placed in parallel before the anaerobic pond in order to receive the sludge from any remaining septic tanks. It is theoretically possible that the primary ponds receive both FS and wastewater, but they would need to be designed for the extra solid load and be built to offer easy desludging. Experience with ponds in developing countries and co-treating wastewater and FS show, however, that desludging of primary ponds does not often work well (Heinss & Strauss, 1999).

5.5.3.2 Site A

One option for a possible location of the WSPs would be at Site A (see Figure 5.6 and 5.7), which is to the north-west of the hospital, about 150 m towards the north-west from the last house at Lower Street. The whole hospital compound, all NTS buildings and about 70% (estimated) of the residential buildings could be connected to the sewerage system (see Figure 5.6). This means that about 30% of the residential areas remain unconnected and have to continue using septic tank systems.

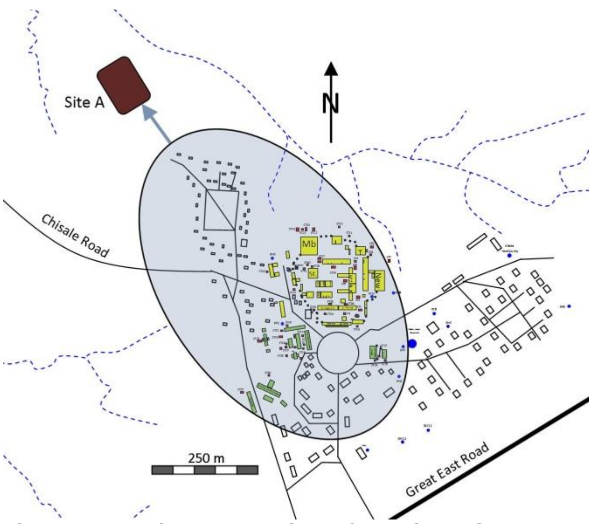

Figure 5.6 – Site A: Location of ponds and approximate coverage area of sewerage system

The length of the main sewer would need to be at least 750 m (from the roundabout to Site A). The level difference between the two points has been measured to be between 7 and 10 m, but could be slightly higher (up to 15 m according to Google Earth).

Figure 5.7 – View of Site A towards north-west. © Mirco Keller.

The possibility to connect any new buildings (such as new NTS buildings and new conference centre) to the sewerage system depends on the location of the buildings. It will be difficult to connect any buildings on the southern end of Chambule Road (as it is probably just outside the coverage area of the ponds). If they are on the northern end of Chambule Road (near new NTS hostel or further north) it should not be a problem to connect them.

The site is fairly flat (with a small hill in the middle) and slopes towards the north-west. Considerable earth works and excavations will be necessary to construct a system of WSPs. Since the site is largely free of vegetation (part of it is used for agriculture) access to the site would not be a problem, nor would there be a need to remove big quantities of trees or bushes.

5.5.3.3 Site B

A second option for locating the ponds would be at Site B (see Figure 5.8 and 5.9), which is to the west of Chambule Road and the NTS buildings, about 150 m to the west of the new NTS hostel. The whole hospital compound, all NTS buildings as well as about 50% (estimated) of the residential buildings could be connected to the sewerage system (see Figure 5.8). This means that around 50 % of the residential buildings remain unconnected and have to continue using septic tank system.

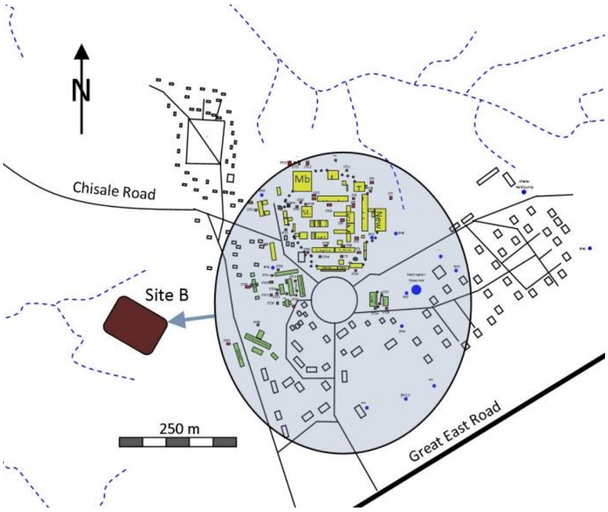

Figure 5.8 – Site B: Location of ponds and approximate coverage area of sewerage system

The length of the main sewer would need to be at least 440 m (from the main hospital entrance to Site B). The level difference between these two points has been measured to be between 6 and 9 m, which is consistent with the data from Google Earth (8 m difference). Since it is expected that more NTS buildings as well as possibly a conference centre are going to be constructed at/near Chambule Road (near Site B), a location of ponds at Site B makes it easier to connect those new buildings to the sewerage system.

The site is fairly flat and slopes gently towards north-west. It is satisfactorily far away from any springs and streams and the area is not used for agricultural purposes. There is no vegetation to speak of and access to the site is ideal (via Chambule Road). The area is prone to being water-logged during the rainy season (it can get swampy at times), but with an appropriate construction of the WSPs, this should not prove to be a problem, once the construction is finished. It is recommended to carry out all excavations and constructions during the dry season.

Figure 5.9 – View of Site B towards north-west. © Mirco Keller.

5.5.3.4 Site Selection

Based on the findings of this study, both sites are considered to be feasible for the construction of WSPs. Both sites are about 150 m away from the closest building and the general wind direction (north) would not create any unwanted odour problems in the hospital or the residential areas. Both sites are fairly flat and the deeper soil (as far as could be analysed) mainly consists of sandy loam with thin layers of silt loam or clay loam.

The decision which of the two sites is more appropriate for SFH depends on various factors. It needs to be decided which (residential) areas have the higher priority to be connected to a new sewerage system, the availability of financial resources needs to be assessed, the exact boundaries of the land which is owned by SFH need to be determined, the locations of any planned new buildings need to be chosen and any other considerations also need to be taken into account.

5.5.3.5 Design

<u>*Sewerage*</u>: The sewerage system covers approximately the areas shown in Figure 5.5 and Figure 5.7 respectively. These areas have been determined on the basis of level differences that have been measured, as well as on visual observations of the site. It is important that the sewers are buried properly, especially if they are made from plastic, in order to reduce the risk of floating and breaking pipes during periods with a high water table. The minimum diameter of the main sewer pipe should be at least 200 mm.

<u>*WSPs*</u>: The anaerobic pond (AP) is sized to treat the volumetric load of the whole area (hospital, NTS and all residential areas) and is 3.5 m deep. The permissible BOD loading has been calculated to be 262 g/m^3/day (after Kayombo et al., 2005), leading to a total AP volume of 1,850 m^3. The facultative pond (FP) is 2 m deep and designed to have a residence time of 30 days. The two (or more) maturation ponds (MPs) are 1.25 m deep and designed to have a residence time of 4 days each. All ponds are rectangular, the length being twice as long as the width. See Table 5.4 and Figure 5.10 for values corresponding to the design flow of Site A and Site B.

Table 5.4 – Design of WSPs at Site A and Site B

	Design flow (m^3/day)	**Volume of AP (m^3)**	**Dimensions of AP (m)**	**Volume FP (m^3)**	**Dimensions of FP (m)**	**Volume of each MP (m^3)**	**Dimensions of each MP (m)**
Site A	588	1850	16 x 33	17,640	66 x 133	2,352	31 x 61
Site B	510	1850	16 x 33	15,300	62 x 124	2,040	29 x 57

<u>*FSPs*</u>: The two Faecal Sludge Ponds (see Figure 5.10) need to be designed to receive the combined organic load (BOD, COD) of both wastewater and FS from any remaining septic tanks (Heinss & Strauss, 1999). The effluent of the FSPs flows into the anaerobic pond; it has been shown that the quality of the FS pre-treatment pond effluent is suitable for discharge into a system of WSPs (Ingallinella et al., 2002). They are used alternatingly: the sludge is disposed in the pond in operation, while the sludge in the other one is left to dewater and dry. Every six months the dried sludge of one pond is removed, after which the mode of operation

is switched. The ponds are expected to be about half the size of the sludge settling ponds for Option 1, therefore each being around 30 m^2 large.

Desludging of AP: The total sludge accumulation of 60 m^3/year on average (see Table 5.3) signifies that it will take about 10 years until the anaerobic pond is one third full and needs to be desludged. It is recommended that a bypass (taking the raw wastewater directly to the facultative pond, see Figure 5.10) is installed to be used during desludging of the anaerobic pond. Another option (not explained in more detail) would be to construct two anaerobic ponds in parallel, which would allow one pond to be desludged while the other one is in use.

Arrangement: Figure 5.10 shows the suggested arrangement and the relative sizes of all the ponds. While the AP has the same size for Site A and Site B, the FP, MP_1 and MP_2 are slightly different; the ponds for Site A are shown in black, the ponds for Site B are shown in red colour.

Figure 5.10 – Design and size of WSPs (black: Site A, red: Site B)

Fence: It is recommended to provide a fence around the ponds to prevent unauthorized people or animals from entering the site.

5.5.3.6 Capital costs

It is assumed that a system of WSPs with a complete sewerage system that serves the mentioned areas costs about the same as the WSP system for Chadiza Hospital, which is approximately 1.6 billion ZMK ($320,000). If Site A is chosen, the system might be considerably more expensive than if Site B is selected, since the distance to the site is longer (more sewers required) and more excavations are required due to its topography.

5.5.3.7 Operation and maintenance

Start-up phase: The anaerobic ponds should be filled with raw sewage and seeded with sludge from septic tanks, after which it can gradually be loaded up to the design-loading rate (Kayombo et al., 2005). It is recommended to start commissioning the ponds during the beginning of the hot season, in order to allow the quick establishment of microorganisms. The facultative pond (as well as the maturation ponds) should be commissioned before the anaerobic ponds; they should initially be filled with freshwater, thereby allowing the gradual development of algae and bacteria (Kayombo et al., 2005). Alternatively, they can be filled with raw sewage and allowed to rest for 3-4 weeks (Varon & Mara, 2004).

Monitoring: Frequent monitoring of the final effluent quality of a pond system is required in order to assess the compliance with discharge standards and to detect any sudden failures.

Maintenance: Regular maintenance of the ponds should be carried out to avoid odours, flies and mosquito nuisances. The following routine maintenance tasks are recommended (Kayombo et al., 2005): Removing screenings and grit from inlet and outlet; Cutting and removing grasses on the embankment; Removing floating scum and macrophytes from the surface of the facultative and maturation ponds; Spraying scum on the surface of the anaerobic ponds; Removing accumulated solids at inlet and outlet; Repairing any damaged embankment as soon as possible; Repairing and damage of the fences or gates. Varon & Mara (2004) recommend one full-time operator for WSPs receiving wastewater flows of up to 1,000 m^3 per day. The anaerobic ponds require desludging when they are one third full with sludge by volume (Kayombo et al., 2005), which has been calculated to be every 10 years for this system. The sludge from the ponds (anaerobic ponds as well as faecal sludge ponds) should be disposed of in a landfill site, agricultural land or other suitable disposal area.

5.5.3.8 Expertise required for O&M

The routine maintenance tasks do not require any special skills; they can be carried out by one operator who is in charge of all the maintenance of the ponds. Since the maintenance is crucial to ensure a smooth operation, a training course for the relevant staff is recommended.

5.5.3.9 O&M costs

Once the system is in place, the expenditures for operating and maintaining it will be very small, as it requires at maximum one full-time operator. In addition to that, about every ten years, the anaerobic pond needs to desludged, which requires a considerable work force. In total, the O&M costs are significantly lower than for Option 1. It is important to point out that a system with WSPs does not cover all of the residential areas. It is expected that about 30% to 50% cannot be connected due to the topography of the site. Considerable maintenance costs will therefore be incurred in order to have a functioning wastewater disposal system for the whole area.

5.5.3.10 Convenience and reliability

The convenience of this system is very good as well. Flush toilets, showers and sinks from inside the buildings can be connected to the sewerage system that takes the wastewater to the ponds. The WSPs are sufficiently far away in order not to create any nuisance to patients, relatives and staff. If the maintenance of the system is not carried out properly, or if a lot of large solid materials are disposed in the toilets (due to a lack of sensitisation), blockages of sewers can occur and cause major problems and public health risks. If the ponds are correctly maintained, manholes are inspected regularly and sensitisation of the users are carried out as recommended the risk of major system failures occurring is very small.

5.5.3.11 Design life

Waste Stabilisation Ponds have a design life of at least 20 years.

6 Conclusions and recommendations

6.1 Conclusions

Research aim: In this report, the research aim – as outlined in section 1.2.1 – has been achieved. The current situation and its main challenges have been assessed, the performance criteria and key factors for the design of a future wastewater disposal system have been determined and the principal options for future wastewater disposal facilities as well as the main criteria for success have been identified.

Methodology: The methodologies that were used (see section 3.1) to obtain the necessary data are considered to be appropriate. A mix of observations, measurements, interviews and secondary data produced the required information in order to be able to draw well-informed conclusions. Throughout the data collection, triangulation of the data was carried out, in order to increase the confidence in the results and to strengthen the completeness of the study.

Situation: The wastewater disposal system of Saint Francis Hospital (including the NTS) consists of 31 septic tanks that are currently in use, most of which (about 24) discharge their effluent in a soak pit. There are at least 44 flush toilets on site, as well as numerous showers and sinks, which all discharge into the septic tanks. Additionally, there are four pit latrines, two of which are frequently used by patients and relatives. It has been found that numerous septic tanks have design faults or are located too close to trees. 70% of the 31 septic tanks are considered to be feasible to empty with an appropriate desludging device. Blockages of toilets and sewers occur frequently in nearly all hospital buildings due to the disposal of large solid materials into the toilets and because of the high groundwater table.

Maintenance: The SFH maintenance team is in charge of maintaining the entire infrastructure of the hospital, which includes the sanitation system. The current maintenance arrangements are very ineffective and rely on reactive rather than preventive maintenance. Nobody is clearly assigned to the maintenance of the sanitation system and the financial resources are very limited. There is a lack of expertise for proper system maintenance as well as a lack of appropriate equipment for emptying the septic tanks. As there are numerous stakeholders involved in the management of SFH, an improvement of the wastewater disposal would inevitably need to be a concerted effort from all stakeholders. Besides the hospital management, the MOH as well as CHAZ are expected to take a leading role.

Principal options: Two principal options for a future wastewater disposal have been identified; Option 1 (see section 6.2.1) involves mainly improving the existing system, while Option 2 (see section 6.2.2) consists of a completely new sewerage system with wastewater treatment facilities. Five selection criteria have been identified in order to choose the most appropriate option: Capital costs; Expertise required for O&M; O&M costs; Convenience and reliability;

Design life. In addition, a number of common areas in need of improvement (see section 6.2.3) have been identified, all of which are of vital importance for any of the two options.

6.2 Recommendations

6.2.1 Option 1: Improving the current system

This option suggests leaving the existing system in place, while its system components are rehabilitated, replaced or improved where necessary. A competent maintenance team with sufficient financial means and the appropriate equipment is put in place. Standardized designs for septic tanks and soak pits are produced in order to ensure a correct construction. An estimated 9 septic tanks, about 10 new soak pits as well as parts of sewers will need to be replaced or newly constructed. Special attention needs to be paid to the high groundwater level, which can inhibit the flow of wastewater if the sewers or septic tanks are wrongly constructed.

O&M: For emptying of the septic tanks, it is recommended to purchase a diaphragm pump, which is much cheaper and easier to maintain than a vacuum tanker. One diaphragm pump should be sufficient as an emptying device for all the septic tanks at SFH. Regarding the disposal of the sludge it is suggested to construct two sludge settling ponds on-site, which can be used alternatingly and can receive the sludge from all septic tanks of the hospital.

Expertise: The skills and the expertise of the maintenance staff need to be developed. It is therefore recommended to provide a professional training course for the relevant employees in order to improve their understanding of the system and its operation and maintenance.

Costs: The total capital costs for this option are estimated to be less than $50,000. It was not possible to estimate the annual O&M costs, but they are assumed to be considerable, due to labour costs, energy (fuel) costs, materials and tools.

Course of action: In order to determine what repairs and rehabilitations need to be done, it is recommended to carry out a detailed assessment of each sewer, septic tank and soak pit as well as monitor the groundwater table at each location. The situation assessment of this report (5.1) and the septic tank survey (Appendix E) can serve as a basis. Once this assessment is completed, the need for repairs, rehabilitations and new constructions can be identified and a more accurate cost estimate for capital costs can be made. Furthermore, it is recommended to make a detailed maintenance plan and schedule. Each septic tank and soak pit should be itemized and the specific maintenance tasks for each should be clearly specified. A work schedule needs to be worked out, containing all maintenance tasks, their frequency, the equipment needed and the staff responsible for it. Defining clear staff responsibilities is crucial in order to ensure a functioning preventive maintenance scheme.

6.2.2 Option 2: Waste Stabilization Ponds

This option entails a completely new sewerage system for the whole area and a system of Waste Stabilization Ponds (WSPs) which finally dispose the treated effluent into a stream. Two sites have been identified for a possible location of the WSPs: Site A and Site B (see Figure 4.1 for locations). Both sites are considered to be feasible due to their location, elevation difference, topography and soil structure. The decision, which of the two sites is more appropriate depends on various factors that are described in section 5.5.3.4.

Remaining septic tanks: Inevitably, due to the topography, there will be a number of septic tanks in the residential areas that cannot be connected to the new sewerage system, but they will still need to be managed and maintained. As it makes sense to treat the sludge together with the wastewater in the ponds, it is recommended to construct two small Faecal Sludge Ponds (FSPs) before the anaerobic pond, which can receive all sludge from the remaining septic tanks.

Design: The WSPs will consist of one anaerobic pond, one facultative pond and at least two maturation ponds. More detailed design recommendations for the WSPs (and the FSPs) can be found in section 5.3.3.5.

Costs: The total capital costs for this option have been estimated to be around $320,000, which is based on the costs for a similar system in a nearby District Hospital. Once the system is in place, the expenditures for O&M will be very small, as it requires at maximum one full-time operator who carries out routine maintenance tasks, as well as about every ten years a desludging of the anaerobic pond. The total O&M costs are therefore considered to be significantly lower than for Option 1.

Expertise: The routine maintenance tasks do not require special skills. Nevertheless, it is recommended to provide a training course for the relevant staff.

Course of action: If this option is chosen, it is important to first carry out precise level measurements with appropriate equipment in order to define the exact location of the ponds, the course of the sewerage system and the exact area that can be served by the ponds. It is important to point out that the construction of a sewerage system always needs to begin at its lowest point (where it empties into the pond) and not at the source where the wastewater is produced.

6.2.3 General areas in need of improvement:

- Prioritizing sanitation: The stakeholders involved need to place sanitation higher on the list of priorities. A commitment to finance and support and improved system is needed.
- Pit latrines: It is recommended to continue with the operation of the 4 existing pit latrines and build 6 more within the hospital premises (see Figure 5.5 for locations). This will

enable all patients and relatives who prefer to use pit latrines instead of flush toilets to do so and also reduce the occurrence of blockages in the sewers.

- Sensitisation: The sensitisation of patients and relatives on how to properly use the toilet facilities is vital in order to ensure a trouble-free operation of the system. This should include information by the nurses to every new patient and relative as well as provision of signs on the walls or doors of the toilet cubicles.
- Toilet cubicles: In total, about 5 – 10 additional toilets are required in order to cater adequately for all people. In the male wards, part of these can be substituted with a number of urinals, which will also reduce the fouling of cubicles. Furthermore, the toilets need to be appropriate for the users; a mix of sit-down and squatting toilets should be provided, depending on the requirements of the patients in each ward.
- Bins: One rubbish bin should be provided in each toilet cubicle and at least one bin near the entrance of the toilet area. All the bins should be emptied frequently.
- Chemicals: The discharge of X-Ray Fixer into a sink needs to be stopped immediately as it is a hazardous substance. Recommendations for its disposal can be found in section 5.2.5. The X-Ray Developer should not be discharged to a septic system, but can be disposed to a sewerage system with wastewater treatment.

6.2.4 Collaboration with EWSC

If Option 1 is chosen, it is not recommended to collaborate with the EWSC for the maintenance of the septic tanks, as their vacuum tanker is prone to break-downs and also fairly expensive to hire. Acquiring a desludging device (diaphragm pump) is therefore considered to be a better solution.

If Option 2 is chosen, a possible collaboration with the EWSC should be considered. This could either be professional support in the design stage of the sewerage and pond system, or a partnership regarding the O&M of the system. The expertise and the capacity of the EWSC would first need to assessed before starting any collaboration.

6.2.5 Criteria for success

As pointed out in the literature review (section 2.2.6.1 and 2.5), the following key factors are vital in order to achieve a functioning sanitation system with a sustainable O&M scheme (adapted from Adams et al., 2008 and Müllegger & Freiberger, 2010):

- The responsibilities for O&M must be clearly defined right from the beginning.
- Appropriate expertise needs to be provided.
- The institution must see the benefit of the system.
- The system must be designed appropriately for local conditions.
- The system must follow design standards and obey legal requirements.

- All stakeholders should be involved in the planning from the beginning of the project, critical design decisions should be made by the users.
- The users need to be sensitized and trained.

6.2.6 Sources of funding

Besides the usual sources of funding (MOH, CHAZ and external organizations from NL and UK), there is another possibility for obtaining funds. The Devolution Trust (DTF) finances and implements projects for improved access to water and sanitation for the urban poor in Zambia (DTF, n.d.). Since SFH qualifies as a peri-urban area (according to MOH and EWSC representatives), it would fall within the coverage of the DTF and a proposal could be made.

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