WATER AND SANITATION FOR HEALTH PROJECT

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ALTERNATIVE SANITATION SYSTEMS FOR THE KENYAN SMALL TOWNS SHELTER AND COMMUNITY DEVELOPMENT PROJECT

WASH FIELD REPORT NO. 161

APRIL 1986

Final Draft
For Review

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Prepared for
the USAID Office of Regional Housing
and Urban Development (Eastern and Southern Africa)
and the National Housing Corporation of Kenya
WASH Activity No. 188

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by

Carl R. Johnson
and
Gregory J. Newman

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TABLE OF CONTENTS

Chapter | Page

DEFINITIONS AND ABBREVIATIONS.................................... iv

EXECUTIVE SUMMARY.. vi

1. INTRODUCTION.. 1

1.1 General... 1
1.1.1 Scope of Work... 1
1.1.2 Objectives.. 1
1.1.3 Report Organization..................................... 1
1.2 Project Setting... 2
1.2.1 RHUDO Kenyan Small Towns Project Goal................... 2
1.2.2 Description of Housing Projects......................... 2
1.2.3 Basis of Planning....................................... 3

2. REVIEW OF APPLICABLE HOUSEHOLD SANITATION SYSTEMS................. 8

2.1 General... 8
2.2 On-site Disposal Systems.................................. 8
2.2.1 Pit Latrines.. 8
2.2.2 Aquaprivies... 10
2.2.3 Septic Tanks.. 12
2.2.4 Soakaway.. 14
2.2.5 Leaching Fields... 14
2.3 Off-site Disposal Sistems................................. 14
2.3.1 Conventional Sewerage................................... 14
2.3.2 Small Bore Sewers....................................... 17
2.3.3 Vacuum and Pressure Sewers.............................. 18
2.3.4 Truck Cartage Systems................................... 18
2.3.5 Wastewater Treatment for Off-site Disposal.............. 20
2.4 Combination Systems....................................... 20
2.4.1 Separate Systems for Sullage and Excreta Disposal...... 20

Chapter		Page
	2.4.2 Stated Development of Sanitation Systems..............	21
3.	SITE DEVELOPMENT CONSIDERATIONS FOR PROCESS SELECTION.............	23
	3.1 General...	23
	3.2 Project Layout and Growth..............................	23
	3.2.1 Lot Size..	23
	3.2.2 Open Communal Space.............................	24
	3.2.3 Population Growth...............................	25
	3.3 Wasteload Considerations...............................	25
	3.3.1 Sullage...	26
	3.3.2 Excreta...	26
	3.3.3 Combined Load...................................	26
	3.4 Physical Considerations................................	27
	3.4.1 Site Topography.................................	27
	3.4.2 Soils...	27
	3.4.3 Groundwater.....................................	28
	3.5 Health Considerations..................................	28
	3.6 Maintenance and Reliability............................	28
4.	PROCESS SELECTION MANUAL..	29
	4.1 General...	29
	4.2 Design Criteria..	29
	4.2.1 Groundwater.....................................	29
	4.2.2 Soil Infiltration...............................	29
	4.2.3 Other Criteria for On-site Disposal..............	30
	4.2.4 Criteria for Sewerage............................	32
	4.2.5 Criteria for Wastewater Treatment and Disposal.........	33
	4.3 Methods for Soil Evaluation............................	33
	4.3.1 Permeability....................................	33
	4.3.2 Groundwater Conditions..........................	35
	4.4 Methods of Wasteload Determination.....................	35
	4.4.1 Population and Growth...........................	35

Chapter		Page

4.4.2 Wasteloads 36

4.5 Sanitation System Selection Algorithm 37

4.5.1 Data Required for Selection 37

4.5.2 Selection Algorithm 39

4.5.3 Technical Feasible Alternatives 39

4.6 Relative Cost Estimating 44

4.6.1 Cost Criteria 44

4.6.2 Illustrative Unit Costs 46

4.7 Final Selection and Design of Sanitation Alternatives 50

TABLES

1. Suggested Hydraulic Loading Rates for Sizing Leaching Fields 6
2. Illustrative Unit Costs (Hypothetical) 48

FIGURES

1. Reed Odorless Earth Closet 9
2. Aquaprivy 11
3. Septic Tank 13
4. Soakaway 15
5. Leaching Field 16
6. Truck and Cartage 19
7. Potential Sanitation Sequences 22
8. Sanitation Alternatives Selection Algorithm 40
9. Example Use of Selection Algorithm 42

REFERENCES 52

DEFINITIONS AND ABBREVIATIONS

Definitions

Effective depth of a drainage trench is the depth of the trench below the perforated drain pipe in the leaching field.

Freeboard is the distance above the water surface to the top of a tank.

Retention time is the average time that fluid is held within a septic tank.

Sullage is used in this report to mean gray water, which is water used for cleaning dishes, clothes, floors, etc., or bathing, but does not include water used for excreta disposal.

Acronyms

KSTSCDP	- Kenyan Small Towns Shelter and Community Development Project
NHC	- National Housing Corporation
RHUDO/ESA	- Regional Housing and Urban Development Office for East and Southern Africa, a branch of USAID
ROEC	- Reeds Odorless Earth Closet
USAID	- United States Agency for International Development
WASH	- Water and Sanitation for Health, a program of USAID

Abbreviations

BOD	biological oxygen demand
cm/day	centimeters per day
ha	hectare
k	permeability mm/day
Kshs	Kenya shillings = approximately $0.10 US
lcd	liters per capita per day
l/day	liters per day
l/m	liters per minute

EXECUTIVE SUMMARY

This report presents a preliminary method for choosing alternatives to conventional sewers for small town housing projects constructed by the National Housing Corporation (NHC) of Kenya. The findings and conclusions of the report are based on a review of pertinent literature on sanitation systems in Kenya and on the National Housing Corporation small town projects. A field visit to Kenya was not within the scope of this investigation, but is recommended for subsequent efforts that may build upon and refine the conclusions developed in this report.

The following alternatives to conventional sewers were found to be practical and feasible for use in small town project sites:

a. Pit latrines for excreta with soakaway, leaching field, or small bore sewers for sullage

b. Septic tank with leaching field for excreta and sullage

c. Septic tank with small bore gravity sewer for excreta and sullage, with off-site wastewater treatment in a stabilization pond

d. Holding tanks for excreta and sullage that are emptied periodically by a truck cartage system, with off-site wastewater treatment in a stabilization pond.

Design criteria for each alternative are presented, and a method is developed for evaluating all of the alternatives and comparing their costs with those of conventional sewerage. The methodology is designed to account for all factors that affect the feasibility and cost of on-site disposal, sewerage, and off-site disposal. These factors include lot size and configuration, overall layout of the small town project area, engineering constraints for on-lot disposal and for sewerage, and requirements for off-site wastewater treatment and disposal.

The methodology presented herein is intended to provide the National Housing Corporation with a preliminary technique for evaluating alternatives to conventional sewers. A list of references is provided for further evaluation and design of the sanitation alternative selected for consideration from the methodology.

This report arose from a request from the National Housing Corporation to the USAID Regional Housing and Urban Development Office (RHUDO/ESA) in Nairobi, Kenya, for assistance in developing low-cost alternatives to conventional sewerage in the Kenya Small Towns Shelter and Community Development Project, which is being financed by USAID. At the request of RHUDO/ESA, a WASH consultant met with the NHC in Nairobi in September 1985 to define the nature of the request. The report was then prepared over the period October to December 1985 by Messrs. Carl R. Johnson and Gregory J. Newman, both of whom are sanitary engineers with Camp Dresser & McKee International Inc.

Chapter 1

INTRODUCTION

1.1 General

1.1.1 Scope of work

This report is intended to assist the USAID Regional Housing and Urban Development Office for East and Southern Africa (RHUDO/ESA) and the National Housing Corporation (NHC) of Kenya in formulating and comparing sanitation alternatives for the Kenyan Small Towns Shelter and Community Development Project (KSTSCDP), which is being financed by USAID. The report briefly reviews applicable sanitation alternatives, presents a method for determining the technical feasibility of each sanitation system discussed, and sets forth a method for comparing the costs of feasible alternatives. The report is based upon a review of existing literature and discussions with WASH personnel.

1.1.2 Objectives

The objective of this report is to present a methodology for evaluating the feasibility and comparing the costs of sanitation alternatives for the Kenyan Small Towns Shelter and Community Development Project. The intent is to present a preliminary design manual for comparing sanitation alternatives.

1.1.3 Report Organization

This report is organized into four chapters. Chapter 1 is the introduction to the report and the Kenyan Small Towns Shelter and Community Development Project. It includes a section relating to general assumptions made about the development project, water use, waste generation, the physical environment, and cultural setting. Chapter 2 presents a brief review of the sanitation systems that are considered potentially applicable to the development project.

Chapter 3 describes the impacts of lot size, population density, project layout, physical characteristics of the site, and other factors related to the feasibility of each of the sanitation alternatives. Chapter 4 presents a step-by-step methodology for determining technically feasible sanitation alternatives and for comparing the costs of these feasible alternatives.

1.2 Project Setting

The following paragraphs describe the Kenya housing projects. The descriptions and assumptions presented are based on literature reviewed pertinent to housing projects in Kenya (Kenya Ministry of Works, East African Engineering Consultants, de Kruijff). These descriptions are used to present examples later in the report. While the assumptions for a particular site may vary from those presented herein, the reader in most cases should still be able to apply the general methodology presented.

1.2.1 RHUDO Kenyan Small Towns Project Goal

The goal of the Kenyan Small Towns Project is to provide adequate housing, affordable to low income groups, particularly in the developing urban areas. The cost of the housing projects, as originally designed, has been escalating to the point that affordability for low income groups has become questionable. The National Housing Corporation has requested an investigation of alternative sanitation systems applicable to these housing projects which might prove more cost-effective than conventional sewerage. RHUDO's goal is to provide guidance to the NHC in selecting and designing sanitation systems for these housing projects.

1.2.2 Description of Housing Projects

The Kenyan Small Towns Shelter and Community Development Project consists of 2 to 16 hectare sites subdivided into individual housing plots, access ways, drainage ways, and communal open space. Water service and sewerage have typically been provided to each housing plot. The development of the plots may be accomplished in stages in accord with the owner's needs and ability to invest. Typically, a plot might be developed in stages from a two-bedroom house with a single shower/water-closet to a five-bedroom house with two-shower/water-closets, living room, and kitchen.

1.2.3 Basis of Planning

This section presents assumptions and generalizations that are made about the housing projects as described in the literature that was reviewed, the physical environment, and the cultural setting. The relative importance of these generalizations and the effect they have upon the feasibility of the sanitation alternatives are discussed in further detail in Chapter 3. It is assumed that the means exist in Kenya to construct and operate each of the sanitation alternatives discussed. The following assumptions are used in examples later in this report. If these assumptions differ from actual conditions for a particular site, the methodology presented in Chapter 4 should be refined using the site specific information.

Project Scale

A typical project site is assumed to be four hectares in area. Approximately 20 percent of this area is communal open space and 25 percent is dedicated to access and drainage ways, leaving 55 percent of the total area for housing plots. Housing plots are assumed to have an area of 294 m^2, as provided in NHC 1974 guidelines (12.5 m by 23.5 m plots). Using these figures, a typical housing site of 4 hectares would contain 75 plots, or approximately 19 plots per hectare.

Population, Water Consumption and Wasteloads

The maximum population density in these housing projects is assumed to be ten persons per plot. That allows for two persons per bedroom on a fully developed plot, or a higher density per bedroom on lesser developed plots. It is also assumed that plots are developed over a number of years. A possible scenario is that 50 percent are developed during the first year and 100 percent are developed in ten years.

Water consumption is estimated at approximately 80 liters per capita per day (lcd) for sites where water service is provided to each house. If only communal sources of water are available, the water consumption would be considerably lower (approximately 25 lcd).

Combined sewage flow (excreta, flush water, and sullage) is assumed to be 80 percent of water consumption. Peak hourly combined sewage flow is assumed to be three times the average daily flow. Excreta is estimated at 120 grams per day dry weight and the following rates are assumed for systems with separate sullage disposal:

- 2 lcd for excreta without flush water
- 5.5 lcd for excreta when anal cleaning is practiced
- 10 lcd for excreta when pour flush fixtures are used

Water Supply and Wastewater Characteristics

Water is delivered through a pipe network to the site and to each household with a minimum pressure head of 20 meters. It is assumed that positive pressure is maintained within the water distribution system at all times. Thus, water supply quality becomes a function of the source and the maintenance of the distribution system. A minimum distance of 100 m between habitations and the water supply source is also assumed. The 100m distance is used to reduce the chance of the water supply becoming contaminated through on-site disposal of excreta and wastewater. The effectiveness of sanitation at providing an adequate level of health is dependent on the provision of clean drinking water. It is expected that wastewaters will have the following approximate characteristics:

	BOD (mg/l)	Fecal Coliform (Number/100 ml)
Sullage	40	4000
Sullage and excreta	300	10^8

General Environmental Setting

A mean monthly temperature of 17^{o} centigrade is typical of the sites. Rainfall ranges from 50 mm/yr to 1500 mm/yr. Little data are available on the soils to be encountered at these sites. Soils are expected to vary from site to site: from sands and gravels to clays, clayey murrams, and weathered rock. Soil infiltration rates are expected to vary widely depending on the type of soil. The preliminary design soil infiltration rate for a disposal system is assumed to be limited to 10 l/m^2-day due to biological clogging of the soil. The basis of this limiting rate is described later in Section 4.2.2. The actual design soil infiltration rate may be adjusted as more site specification information becomes available. Table 1, on the following page, presents some typical infiltration rates for various types of soils.

General Cultural Setting

The selection of a sanitation system is a complex subject requiring study of people's attitudes, current practices, a willingness to change, and health education. A pilot program is useful for evaluating a system before embarking on a large-scale program. It is not within the scope of this report to incorporate these concerns within the selection methodology. The following paragraph, however, presents assumptions made about the general cultural acceptability of the sanitation technologies discussed herein.

Conventional sewerage is assumed to be an acceptable technology, both to the home owners and to the construction personnel. In general, the alternatives described will require increased levels of maintenance by the home owners as compared to conventional sewerage. It is necessary that the home owner be educated in the proper maintenance procedures for the sanitation technology used. These sanitation technologies generally require less skill on the part of construction personnel. It is assumed that communal water closets are unrealistic given cultural attitudes about privacy. Maintenance of water closets serving more than one household would require routine and rigorous cleaning

Table 1

Suggested Hydraulic Loading Rates for Sizing Leaching Fields

Soil Type	Suggested Hydraulic Loading Rate*	
Sands	5.0 cm/day	(50 l/m^2-day)
Silt-Loams and Silty-Clay Loams	5.0 cm/day	(50 l/m^2-day)
Fine to Medium Sands	3.4 cm/day	(34 l/m^2 day)
Sand-Loans, Loams	3.0 cm/day	(30 l/m^2-day)
Clay-Loams	1.4 cm/day	(14 l/m^2-day)
Clays, some Clay-Loams	0.6 cm/day	(6 l/m^2-day)

*These loading rates are for soils with intermediate rates of permeability. For very high permeability soils, and for very low permeability soils, consult references at the end of this report regarding design limitations for soil absorption.

Source: Griffin (1984).

procedures and would represent a potential health hazard. Reuse of sterilized excreta is not being proposed in any of these alternatives. Some documentation of the unacceptability of pit latrines exist; that is, there is the fear that children may fall in or that snakes or rats may be able to enter the house through the pit latrine. All of the technologies described in this report use openings that would be too small for a child to fit through. In most cases, rats or snakes can beeliminated by chemical treatments, proper construction, and maintenance of the facility.

Chapter 2

REVIEW OF APPLICABLE HOUSEHOLD SANITATION SYSTEMS

2.1 General

This chapter briefly describes applicable sanitation systems for the Kenyan Small Towns Shelter and Community Development Project. It is intended neither as an exhaustive review of disposal technologies nor as a design manual for these technologies. The reader is directed to more detailed design documents for the final design of each sanitation technology. Chapter 4 presents a methodology for sanitation technology selection.

2.2 On-site Disposal Systems

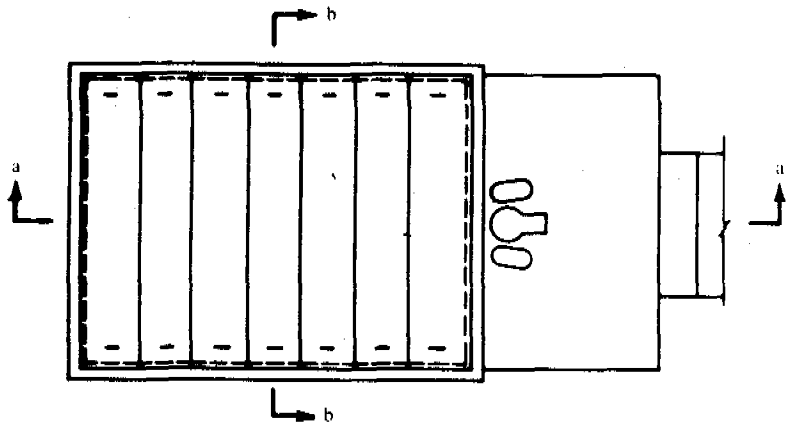
2.2.1 Pit Latrines

Pit latrines have three major components: a pit for collection of excreta, a squatting plate (or raised seat, pour-flush waterseal, etc.), and a superstructure. In practice, the pit is filled with excreta until it is approximately three-fourths full (750mm from slab to the latrine contents for a 3m deep pit), at which time the excreta is either removed, or the latrine is moved to a new location and the former pit is covered with soil. As a result of space limitations and the relative permanence of the housing projects, a movable pit latrine is not presented as an applicable option for the KSTSCDP. Figure 1 presents a Reed Odorless Earth Closet (ROEC). The ROEC type of pit latrine is presented in this report as an example, although the actual pit latrine selected for design may vary to meet site specific considerations and history of local acceptance. The ROEC has the following advantages and disadvantages:

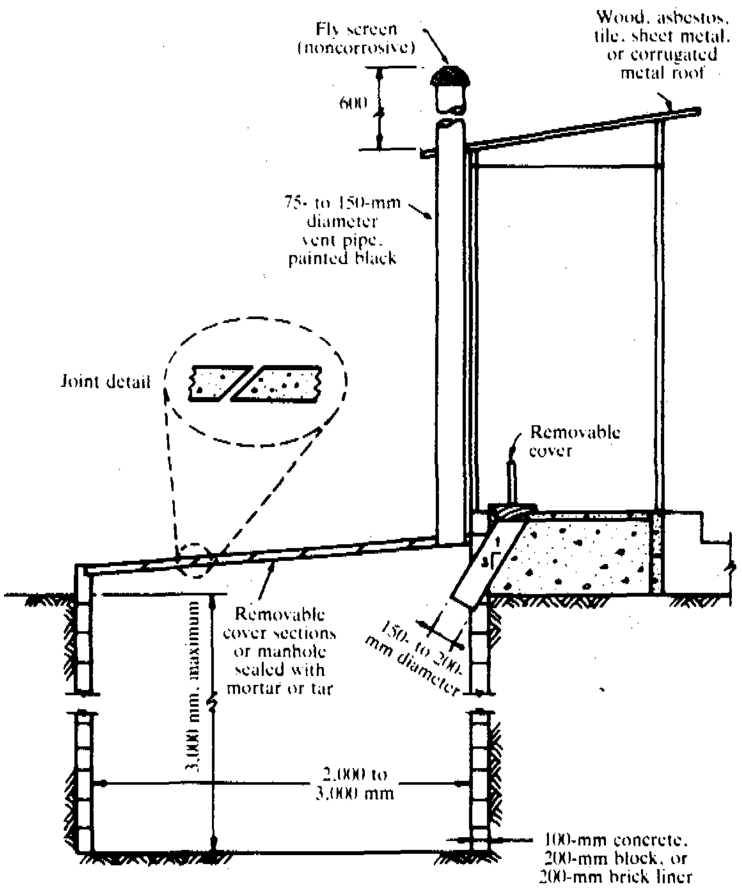
Advantages

1. The offset pit allows for greater pit volumes; thus, the latrine lasts longer.

A. Plan



Plan (with latrine superstructure removed)



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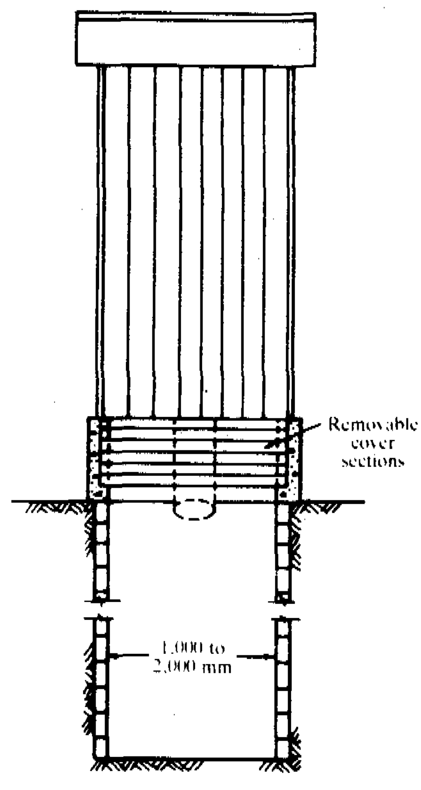


Section b-b (vent not shown)

Source: Kalbermatten et al. (1982).

Figure 1. Reed Odorless Earth Closet

2. The manhole to empty the pit can be placed outside the house to facilitate access.
3. It is easily constructed and maintained.
4. It has a low annual cost.
5. Only small amounts of water are required.
6. There are minimal risks to health.
7. There are minimal problems with odors, flies, and mosquitoes.
8. It is easily upgradeable to a pour-flush, sewered system in the future.

<u>Disadvantages</u>

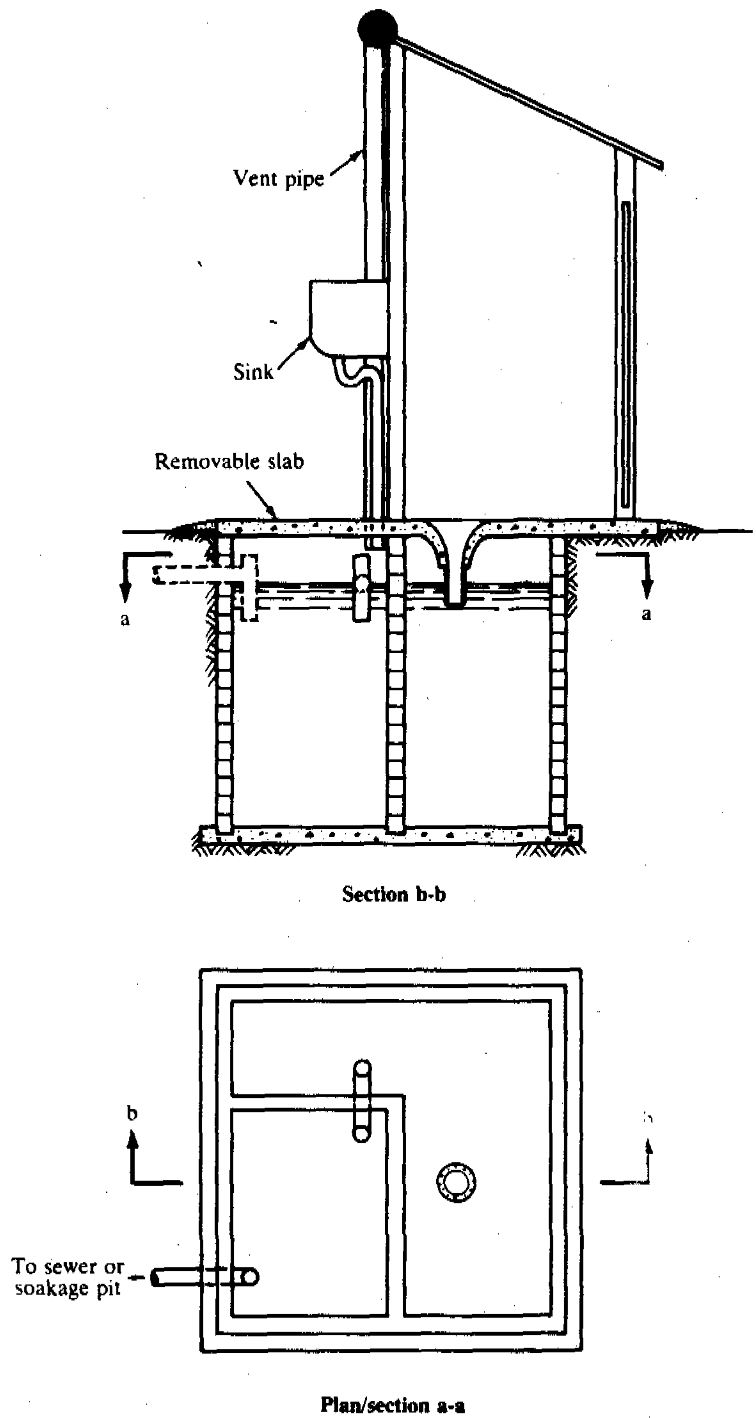
1. Pit latrines are generally unsuitable for areas with high population densities because such latrines can pollute local groundwater supplies.
2. Separate arrangements must be made for sullage disposal.
3. It is difficult to construct in rocky areas or areas of high groundwater.
4. The ROEC type of pit latrine may require periodic cleaning of the chute.

2.2.2 Aquaprivies

The aquaprivy consists of a superstructure and a squatting plate above a small septic tank which discharges effluent to a soakaway, leaching field, or sewer system. As shown in Figure 2, the squatting plate has a drop pipe which is submersed 100 to 150 mm below the water level in the tank. Maintaining this water seal is critical to the proper functioning of this sanitation system. Excreta are decomposed anaerobically in the tank. The tank has a removable cover, outside of the house, which is accessible for cleaning the tank.

<u>Advantages</u>

1. Sullage can be delivered to the tank to maintain the water level.



Source: Kalbermatten et al. (1982).

Figure 2. Aquaprivy

2. When used with a soakaway or drainfield, it is easily upgradeable to a sewered system.

Disadvantages

1. If the water seal is not maintained, severe problems with odors, flies, and mosquitoes can result.
2. The tank must be watertight and is expensive to build.
3. This system requires a soakaway or leaching field with adequate area for on-site disposal.

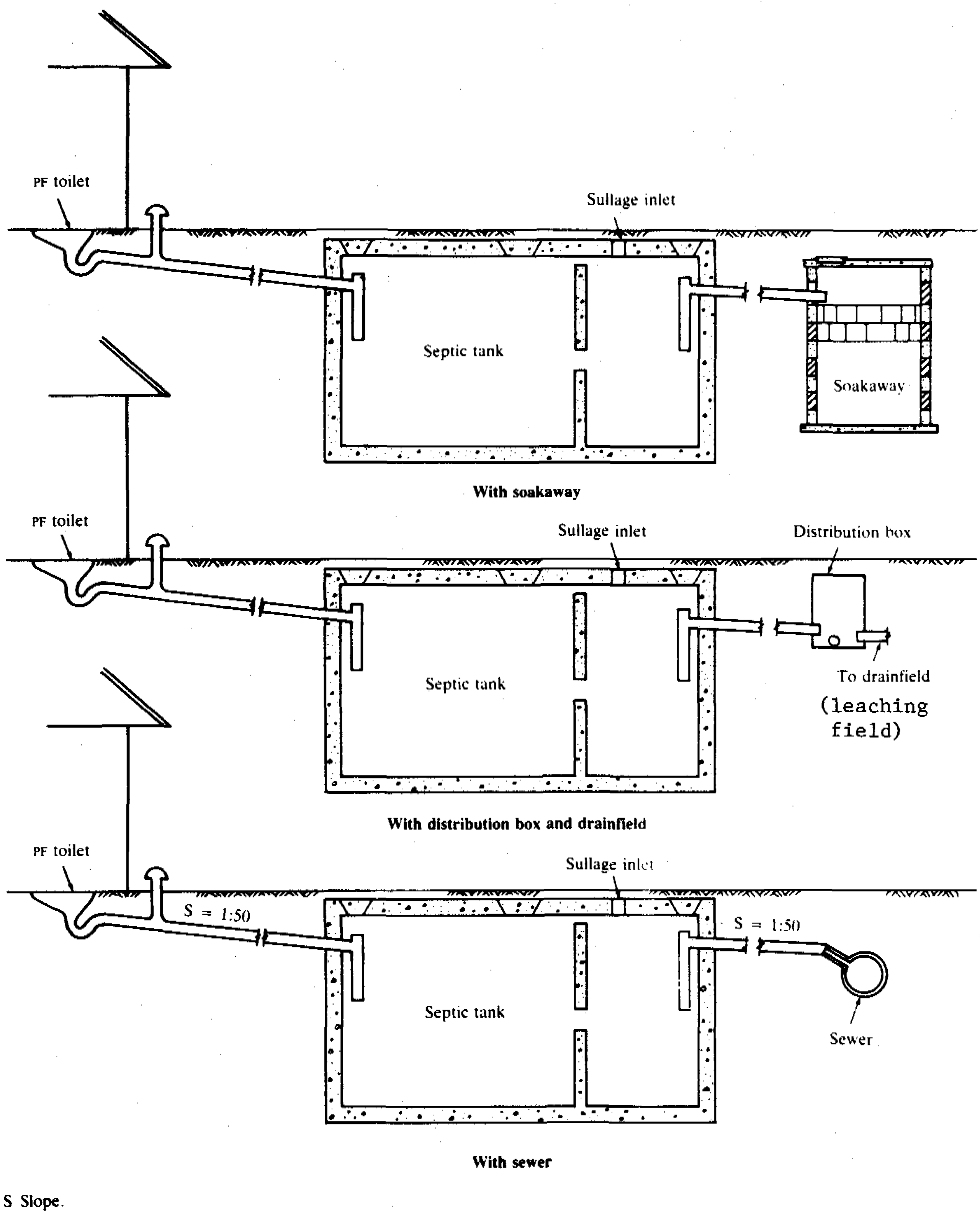
The aquaprivy is not recommended as an applicable option because of potential malfunctions of the system when the water seal is not maintained. A failure in the water supply system would probably result in widespread failure of these systems with associated health risks and release of anaerobic gases.

2.2.3 Septic Tanks

Septic tanks are rectangular underground chambers which decompose excreta anaerobically. They are usually designed to receive excreta and flush water and sullage. Solids (sludge) settle to the bottom of the chamber and must be removed periodically. The effluent from the chamber (septage) is disposed of by way of a soakaway, leaching field, or sewer to a treatment facility. For the purpose of this report a two-compartment septic tank, as shown in Figure 3, is recommended due to the increased reliability of this system as compared to a single compartment tank.

Advantages

1. Septic tanks will take sullage as well as excreta.
2. Septic tanks work well with a pour-flush fixture, further minimizing health risks.
3. Disposal may be upgraded to conventional sewers or small bore sewers at a future date.



Source: Kalbermatten et al. (1982).

Figure 3. Septic Tank

Disadvantages

1. Septic tanks require a minimal flushing flow to move excreta through the inlet pipe.
2. Concrete construction of the tank is relatively expensive.
3. The sludge must be removed periodically.
4. A large area for on-site effluent disposal is required.

2.2.4 Soakaway

A soakaway consists of a pit with improved drainage features to facilitate infiltration of wastewaters into the soil, as shown in Figure 4 on the following page. The use of soakaways and leaching fields is restricted by space requirements and the ability of the receiving soil to allow water to percolate away. High groundwater conditions may make both soakaways and leaching fields infeasible.

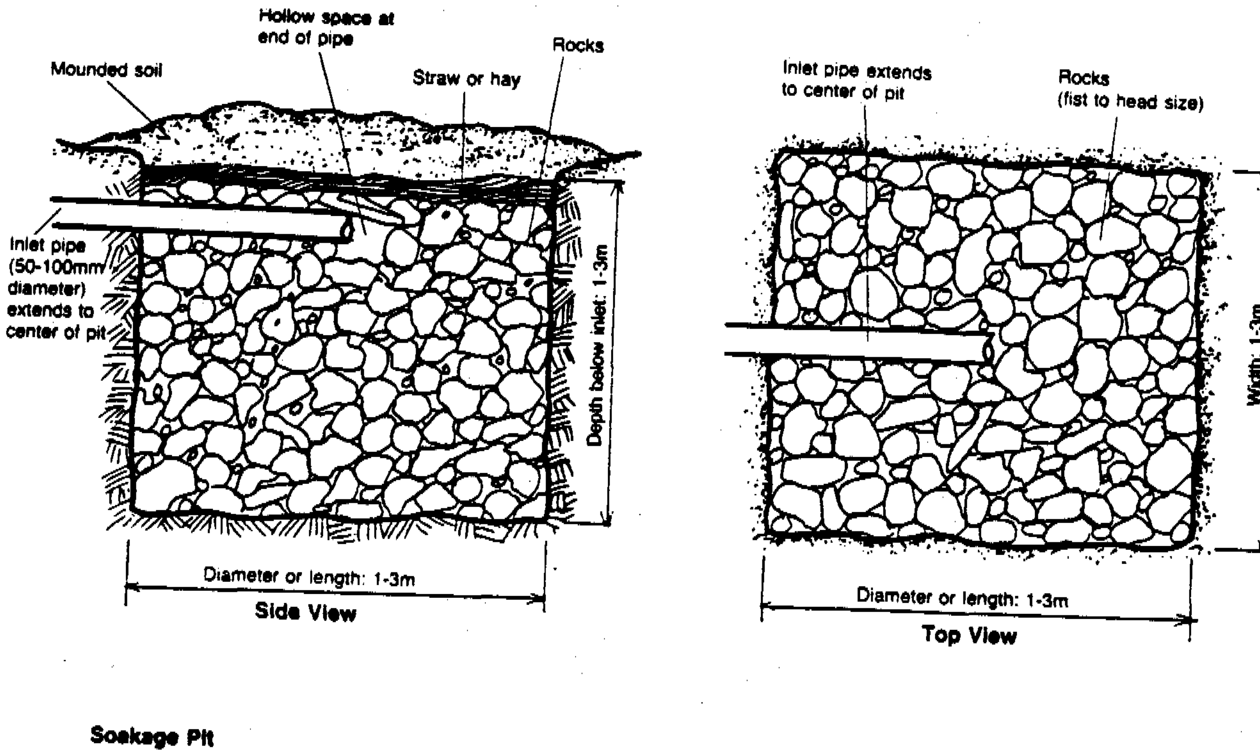
2.2.5 Leaching Fields

A leaching field consists of a distribution box with lateral perforated drainage pipes placed in trenches with improved drainage features to facilitate the infiltration of wastewater into the soil, as shown in Figure 5.

2.3 Off-site Disposal Systems

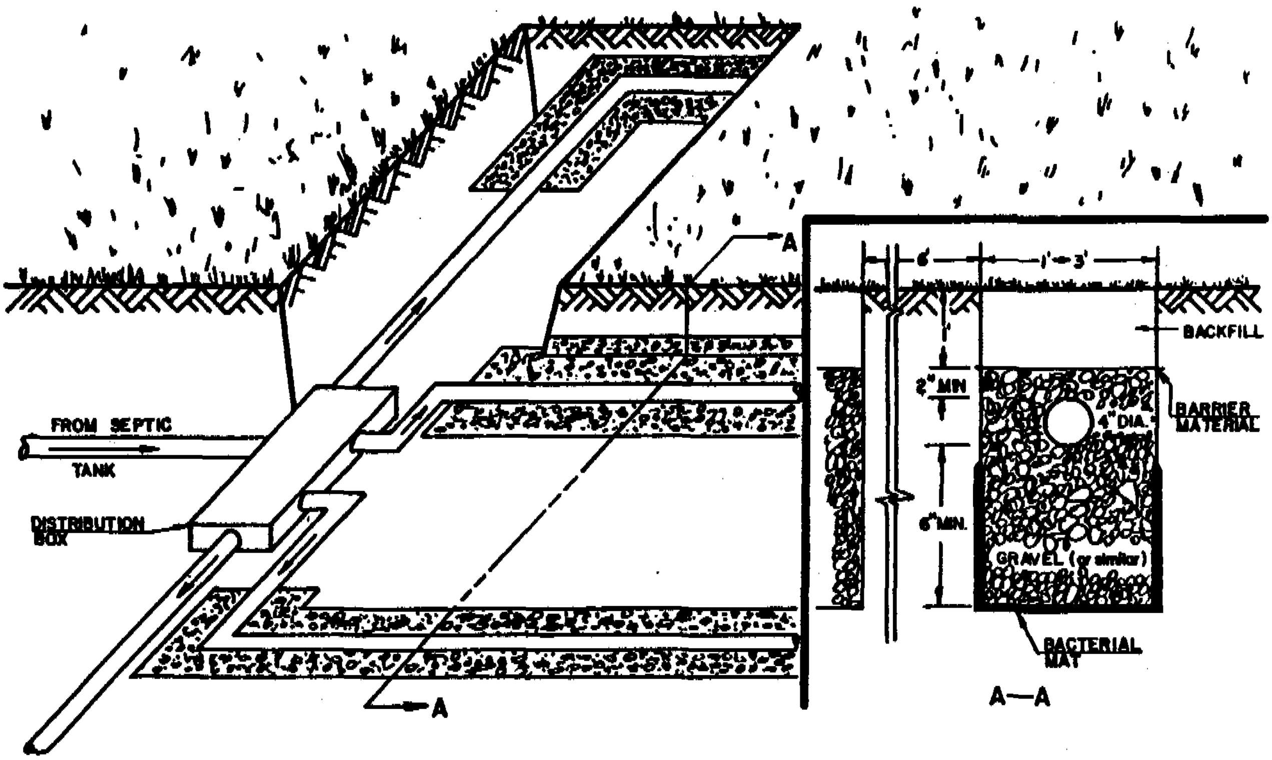
2.3.1 Conventional Sewerage

Conventional sewers are designed to transport a mixture of excreta and sullage from the home to a treatment facility through a pipe network. Generally, the pipes are designed to function by gravity flow. A minimum flow velocity is required (achieved by constructing the pipe with an adequate slope) to suspend solids and prevent clogging of the pipes. To keep excavation costs down, a site with a slight grade is preferable. Pumping stations may be required in flat areas or to move flows contrary to the land gradient.



Source: USAID, Water for the World Technical Note SAN 1.D.7.

Figure 4. Soakaway



Source: Griffin (1984).

Figure 5. Leaching Field

Advantages

1. This system requires little maintenance by the user.
2. Health risks, with a properly functioning system, are minimal.
3. This system permits the discharge of large amounts of wastewater, thereby making it easier to promote the use of water to improve sanitation practices (that is, bathing, handwashing, etc.).

Disadvantages

1. Conventional sewerage has high initial costs.
2. It requires skilled contractors to construct.
3. This system requires a treatment facility off the site, which also has associated costs.
4. This system requires a municipal organization to maintain and operate the sewer, pumping system, and treatment facility, which may have a high recurrent cost to the community.
5. Sewer pipes are prone to clogging or become septic if water use is less than 75 lcd, or unless a regular program of sewer flushing is conducted.

2.3.2 Small Bore Sewers

Small bore sewers are designed to transport settled sewage and sullage only. This alternative requires a pipe network to deliver flows to a treatment facility. The pipes transport flows by gravity. Pipes can be laid at flatter grades than conventional sewers because the minimum velocity required to maintain solids suspension is less. Typically, the wastewater carried in small bore sewers consists of settled effluent from septic tanks, soakaway overflows, or other holding units.

Advantages

1. Fewer manholes are required than for conventional sewers, thereby resulting in cost savings.

3. It is easily upgraded with either small bore sewers or conventional sewers.

Disadvantages

1. This system has a high level of user maintenance required.
2. Annual costs are high for labor and fuel or trucking fees.
3. The lots must be accessible to the tanker trucks.
4. If reliable trucking services do not exist, then a municipal organization would be required to purchase and maintain the sewage trucks. The management required may be considerable.
5. Overflowing vaults present a health hazard.

2.3.5 Wastewater Treatment for Off-site Disposal

Off-site disposal systems require a treatment facility in either an adjacent or neighboring locality. For the purposes of this study, the simplifying assumption is made that land is available for treatment facilities and that waste stabilization lagoons would be used as part of project development.

2.4 Combination Systems

2.4.1 Separate Systems for Sullage and Excreta Disposal

When pit latrines are used, a separate system for sullage disposal must be employed. If soil infiltration rates permit, on-site disposal of sullage may be achieved by using either a soakaway or a leaching field. If soil infiltration rates are too low, or the infiltration bed becomes clogged, sullage may be disposed of off-site by way of small bore sewers.

Advantages

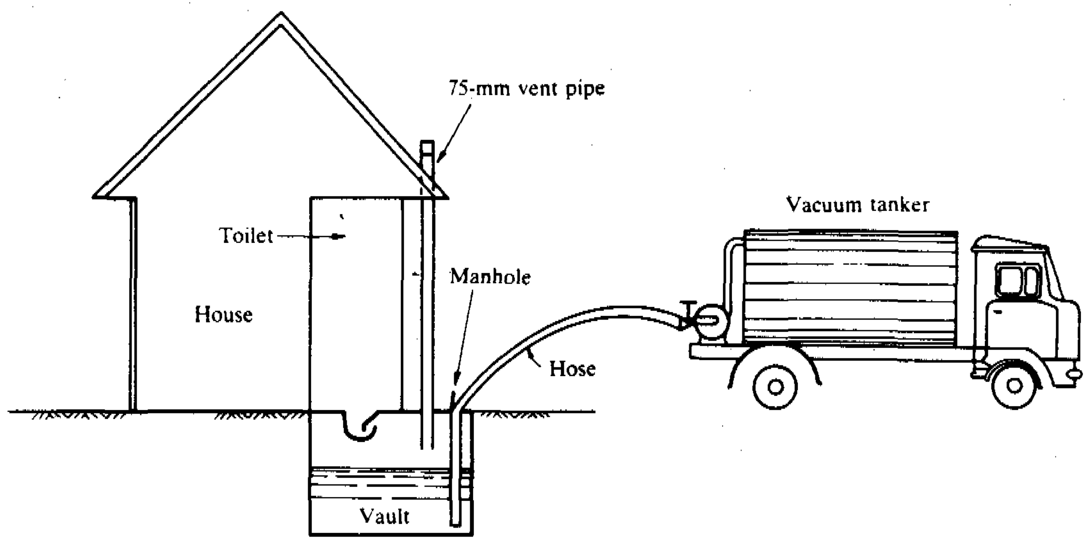
1. Separate systems have a low initial cost for excreta disposal.
2. As a site is developed for water supply, the increase in sullage waste may be disposed of independent of excreta disposal.

Disadvantages

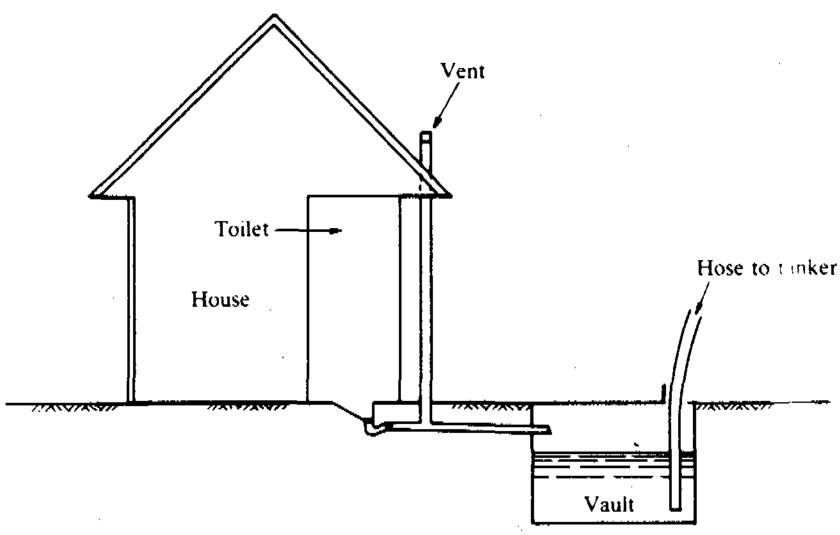
1. Pit latrines require maintenance and periodic emptying.
2. Disposal of sullage will require installation of sand and grease traps.
3. Off-site disposal of sullage requires an off-site treatment facility which has associated costs and requires a municipal organization to maintain and operate the small bore sewer system and the wastewater treatment facility.

2.4.2 Staged Development of Sanitation Systems

The staged development of sanitation systems can be employed to take advantage of initial low cost solutions (appropriate for the initial population and wasteloads generated), which would be inadequate for a fully developed site. Staged development may also be considered as an upgrading sequence when the economic capability of the home owners increases. Figure 7, on the following page, presents some potential sanitation sequences based upon the level of water service. Other potential sequences may occur in response to the clogging of infiltration beds or an increase in wasteloads as plots are developed. An example would be a communal septic tank and leaching field upgraded to a sewer system as all of the plots are developed and the quantity of wasteloads increase.



Vault below squatting plate



Offset vault

Source: Kalbermatten et al. (1982).

Figure 6. Truck and Cartage

2. Pipe slopes and depths are less restrictive than for conventional sewers, thereby making excavation and construction less expensive.
3. An opportunity exists to upgrade to this alternative from on-site disposal systems which have clogged infiltration beds.

Disadvantages

1. This system may require the installation of sand and grease traps, particularly when sullage is to be transported.
2. This system requires a treatment facility off the site, which also has associated costs.
3. This system requires a municipal organization to maintain and operate the sewer system and treatment facility.

2.3.3 Vacuum and Pressure Sewers

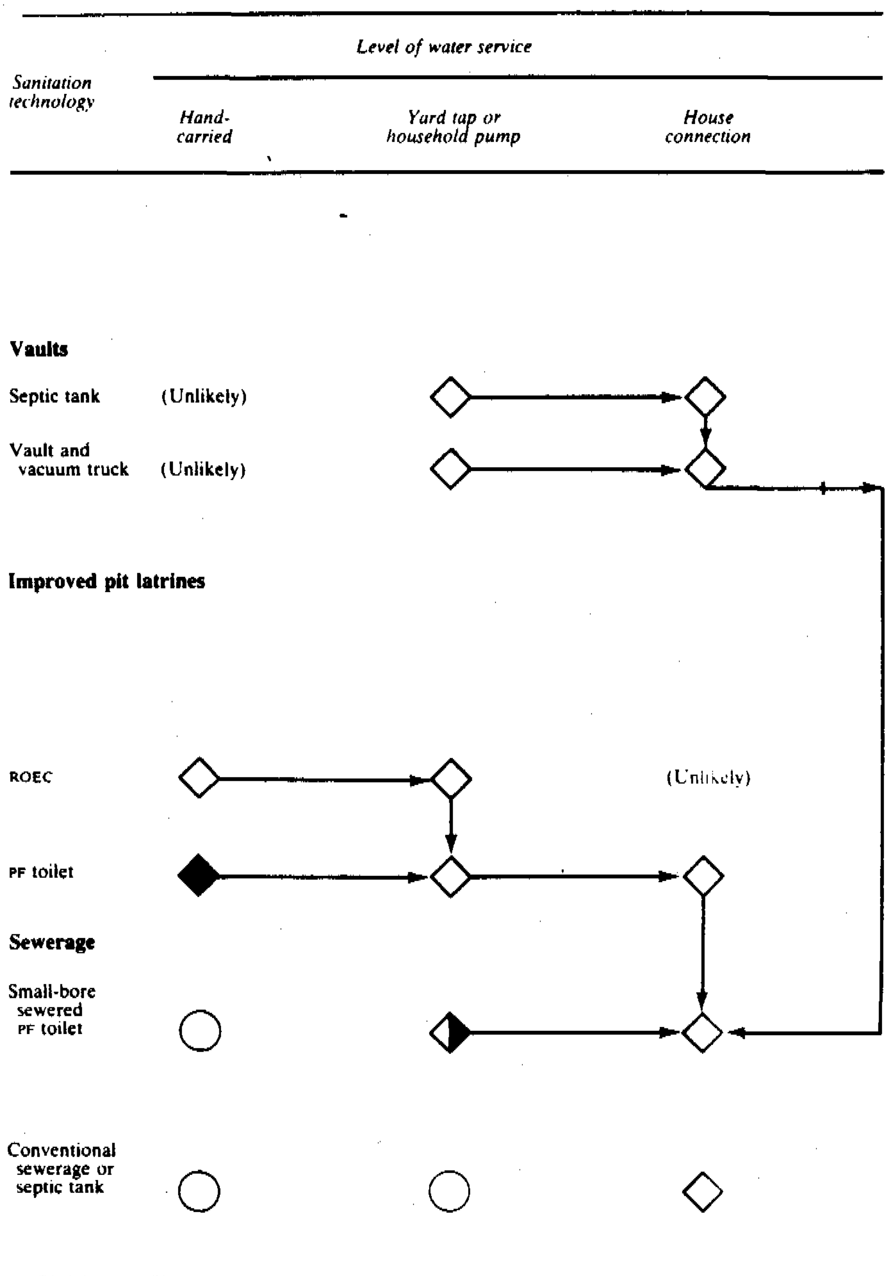
Vacuum and pressure sewers convey sewage by an artificially induced energy gradeline. Flows may be delivered to a gravity sewer or a treatment facility. The major advantage of this type of system is that the pipes do not need to follow specific gradients. It has many disadvantages related to high construction, operation, and maintenance costs. These types of systems are not considered appropriate for the Kenyan Small Towns project at this time and are, therefore, not considered further in this report.

2.3.4 Truck Cartage Systems

A truck cartage system consists of a vault for collecting excreta and sullage which is periodically emptied by a vacuum tanker truck, as shown in Figure 6 on the following page. The tanker trucks then transport the wastewater to a sewer or treatment facility.

Advantages

1. This system has relatively low construction costs.
2. It has a low on-lot land area requirement.



◇ Technically feasible.
◆ Feasible if sufficient pour-flush water will be hand carried.
○ Technically infeasible.
◆ Feasible if total wastewater flow exceeds 50 liters per capita daily.

Source: Kalbermatten et al. (1982).

Figure 7. Potential Sanitation Sequences

Chapter 3

SITE DEVELOPMENT CONSIDERATIONS FOR PROCESS SELECTION

3.1 General

This chapter describes how the establishment of lot size, population density, overall development layout, and other factors affect the feasibility of providing the previously discussed sanitation technologies. Assumptions are made about each of these factors for illustration purposes. It is expected that the methodology presented will be refined using site specific information.

3.2 Project Layout and Growth

3.2.1 Lot Size

The lot size may determine the feasibility of on-site disposal systems. The following design example for a leaching field illustrates this point.

Leaching Field Design Example

Assumptions: Water supply source located off the site
Water consumption = 80 lcd
Wastewater flow = 80% of water consumption
Maximum persons per plot = 10
Depth to high groundwater > 2 m
Permeability (k): k > 10 mm/day
Limiting infiltration = 10 l/m^2-day
Safety factor = 1.5
House area = 120 m^2
Reserve area around house and lot = 80 m^2
(area reserved for trees, walkways, carriage ways, septic tank, separation of leaching fields, and other structures, not including the leaching field)

$$\text{Leaching Field Area} = (10\ \text{pers})(80\ \text{lcd})(0.8)(1.5)/(10\ \text{l/m}^2\text{-d})$$
$$= 96\ \text{m}^2$$

The total lot area required for an on-lot leaching system is 296 m^2 (house area plus reserve area plus leaching field area). This indicates that the standard lot size of 294 m^2 is marginally adequate for on-site disposal given the assumptions made in this example. Smaller lots would be incapable of on-site treatment. Larger lots would allow a greater margin of safety and thus more reliable service for on-site disposal systems.

3.2.2 Open Communal Space

The area allotted as open space could potentially be used as a communal on-site disposal facility; that is, a communal subsurface leaching field with a recreational use on the ground surface. In Chapter 1, it was assumed that 20 percent of the housing site would be dedicated to communal open space. On a fully developed hectare (19 lots), it can be calculated that 0.18 ha is required for wastewater absorption (96 m^2 x 19). Because the assumed site layout provides only 0.2 ha of open space per hectare, all of the open space would be dedicated to the leaching field. This leaves no space for distribution boxes, septic tanks, trees, and other structures. It is recommended that only half of the open space be used as a leaching field. Thus, it is concluded that either the percentage of the site dedicated to open space must be greater, or the population density (and corresponding waste flow) must be less, in order to use the open space for on-site disposal reliably.

It is possible that the open space could be used in a staged sequence as a temporary on-site wastewater disposal facility prior to 100 percent development of the lots on a housing site. If a site develops slowly, it is possible that a communal septic tank and leaching field may be appropriate for a period of years while many lots are undeveloped. After some years the total waste flows may become too great and the system can then be upgraded to a sewered system, thereby postponing the higher costs of a sewered system.

3.2.3 Population Growth

A maximum population density of ten persons per lot has been assumed. If the maximum population density is actually greater or less, there would be an increase or decrease, respectively, in the area requirements for on-site disposal. The design population density will affect the feasibility of certain sanitation technologies.

The rate of population growth plays a significant role in determining the feasibility of staged sequences of sanitation alternatives. As demonstrated in the previous two sections, the housing sites have a limited capability for on-site disposal of wastewater when fully developed due to the land requirements of soil absorption. Prior to maximum development of the sites, however, the population density and corresponding wastewater flows may be much less, thereby decreasing the land requirements for the soil absorption units. If population growth in the housing sites is slow, temporary on-site disposal systems may be feasible. The temporary on-site disposal system can be upgraded to a sewered system, if necessary, at a later date.

The rate at which these housing sites are developed also affects the feasibility of sewering systems. Sewers require minimum flow velocities to prevent clogging. If the rate of population growth and utilization of the site is slow, then minimum velocities may not be achieved on a regular basis and the sewer system may require periodic flushing during the initial years of a housing project.

3.3 Wasteload Considerations

It has been assumed that water is supplied to each house, resulting in an estimated water consumption of 80 lcd. However, actual consumption may be as low as 25 lcd if communal water service is provided instead of house connections. The result would be a drastic decrease in the expected wastewater flows which affects the feasibility of various sanitation alternatives. It has also been assumed that there will be a maximum of ten persons per lot. A higher or lower maximum number of persons per lot would increase or decrease, respectively, the expected wastewater flows.

3.3.1 Sullage

The actual amount of sullage produced affects the feasibility of using soakaways, leaching fields, and small bore sewers. Soakaways are generally feasible when sullage flows are less than 250 l/day. The area required for a leaching field is directly proportional to the wastewater flow to be absorbed by the soil. A higher sullage flow requires more leaching field area and may limit the use of a leaching field for disposal of sullage. Small bore sewers must sustain a minimum flow velocity (0.3 m/s) on a regular basis to function properly. If the sullage produced is less than 25 lcd, there exists a high probability of small bore sewer system maintenance problems, unless a sewer flushing program is instituted.

3.3.2 Excreta

Generally, it can be assumed that excreta production is within the range of 0.6 to 0.9 m^3/person-yr. In this report 0.7 m^3/person-yr has been assumed. The amount of excreta produced affects the size of pit latrine required. The pit latrine can be sized for yearly cleaning, based upon the expected rate of excreta accumulation within the pit. For the purposes of this report a pit latrine sludge accumulation rate of 0.1m^3/person-year is assumed. Excreta production also affects sludge production in septic tanks and, consequently, plays a similar role in the selection of septic tank size and period of pumping. A sludge accumulation rate within septic tanks of 0.04 m^3/person-year is assumed.

3.3.3 Combined Load

The combined wastewater production per household may determine the feasibility of conventional sewers. Conventional sewers are designed to achieve a theoretical minimum velocity of 0.6 m/s on a regular basis in order to prevent clogging. If the wastewater flow is less than 75 lcd, there exists a high probability of conventional sewer system problems. The combined wastewater load also affects the sizing of the vault and the frequency of vault pumping for vacuum truck cartage systems.

3.4 Physical Considerations

3.4.1 Site Topography

It is assumed that the housing sites are situated on flat or gently sloping terrain. Flat sites will increase the cost of conventional sewer systems. Gently sloping sites are optimum for most sanitation alternatives. Steep sites increase the likelihood of failure for on-site disposal systems. Steep slopes may have steep groundwater gradients and raising of the groundwater locally may (1) decrease slope stability over the long term and (2) create an opportunity for polluted springs to well up.

3.4.2 Soils

Generally, rocky soils or hardpan soils pose construction problems for each sanitation alternative. In rocky soils, preference will go to alternatives which require less excavation. The permeability of the soils may determine the feasibility of on-site disposal systems, that is, soakaways and leaching fields. Soil infiltration of wastewater is dependent upon soil characteristics and is affected by the development of a biological layer within the drainage pit or trench. Poor permeability or percolation rates may make infeasible the use of on-site sullage disposal via leaching fields or soakaways. The long-term acceptance rate (hydraulic loading rate) of a leaching field is dependent upon the ability of wastewater to infiltrate through the biological layer which develops in the surrounding soils. Table 1 lists soil types with typical permeabilities and their suitability for on-site disposal.

3.4.3 Groundwater

Groundwater elevation plays an important role in determining the feasibility of on-site disposal systems. The high groundwater elevation should be at least a meter below the bottom of a drainage facility. High groundwater may result in the flooding of leaching fields, soakaways, and septic tanks and, consequently, may create a health hazard. High groundwater should also be taken into account when designing conventional sewerage systems. Sewer pipes should be sized to carry the higher levels of infiltration that result from high groundwater.

3.5 Health Considerations

Sanitation systems which permit greater water consumption (that is, sewers) will help to promote better sanitation practices (that is, bathing and hand-washing) by using more water, which may improve health. Pour-flush systems help prevent the spread of disease by creating a water seal which aids in preventing flies and mosquitoes from breeding in excreta and entering the house. Proper use and maintenance of the systems discussed will promote a healthy environment. The relative reliability and the impact of a system failure, however, should be considered. An individual on-site disposal system may be more likely to fail due to poor maintenance, but such a failure will have fewer health implications than a failure of a shared facility.

3.6 Maintenance and Reliability

Reliability of the previously described systems is a function of design, construction, and maintenance. It is assumed that the quality of design and construction will be consistent regardless of the alternative selected. It should be noted, however, that conventional sewers do require a higher degree of skill to design and construct properly than the other systems. Reliability of each system may be most easily related to the degree of user maintenance required. The vacuum truck cartage system and systems which use septic tanks or pit latrines may be considered less reliable due to the high degree of maintenance required.

Chapter 4

PROCESS SELECTION MANUAL

4.1 General

This chapter presents a methodology for evaluating the technical feasibility of the sanitation systems identified in Chapter 2. It also presents a method to compare the cost-effectiveness of those systems identified as being technically feasible.

4.2 Design Criteria

This section summarizes the design criteria pertinent to evaluating the technical feasibility of the various sanitation alternatives.

4.2.1 Groundwater

High groundwater conditions may necessitate the use of conventional sewerage or a cartage system due to potential flooding of on-site disposal schemes. The depth to high groundwater should be at least 1.0 m for pit latrines, septic tanks, vaults, and leaching fields. In addition, the depth to groundwater should be at least 1.0 m below the bottom of a soakaway (typically, depth to high groundwater should be greater than 3.0 m).

4.2.2 Soil Infiltration

Sizing of the leaching field should be based upon the long-term soil infiltration (acceptance) rate, which generally is within the range of 10 to 30 l/m^2 day (see Table 1). Because percolation tests essentially indicate the infiltration rate of clean water into virgin soil, a design infiltration rate of 10 l/m^2 day is recommended, (Kalbermatten, 1982) unless a more accurate figure is known from local experience. This lower design infiltration rate anticipates a reduction in soil infiltration due to biological mat formation.

4.2.3 Other Criteria for On-site Disposal

Water Use

Water consumption should be less than 25 lcd for design and construction of soakaways to be practical. Although septic tanks and leaching fields are not constrained by water use, they do work better at flows greater than 25 lcd.

On-site Disposal Area Requirements

The area required for on-site disposal may be estimated as follows.

$$A = (s.f.) \times Q_{w/I}$$

Where:
A = area required (m^2)
(s.f) = safety factor (use 1.5)
Q_w = wastewater flow (l/day) (see section 4.4.2)
I = limiting infiltration rate (10 l/m^2-day)

Sizing Leaching Field Drainage

The length of leaching drains can be determined as follows.

$$L = A/2D$$

Where:
L = drainage pipe length (m)
A = disposal area required (m^2)
D = effective depth of drainage trench (m)

Drainage pipes in parallel should maintain a minimum distance of two meters between centerlines of drain pipes.

Sizing Soakaways

$D = A/C$

Where:

D = effective depth (2 to 3 m)

A = disposal area required (m^2)

C = circumference (m)

= 3.14 x diam, for circular

= 4 x side length, for square

Sizing Septic Tanks

The required volume is determined by comparing $V_{min.}$ to $V_{init.}$

$V_{min} = W \times D \times L$

$V_{init} = Q_w \times R \times 0.001$

$N = (2/3) \times V_{req}/(S \times P)$

Where:

V_{min} = minimum tank size (m^3)

V_{init} = tank size based on retention time (m^3)

V_{req} = required volume (m^3)

W = tank width (m) (min = 1 m)

D = tank depth (m) (min = 1 m)

L = tank length (m) (L/W = 2-3)

Q_w = waste flow (l/day) (see section 4.4.2)

R = tank retention time (days) (R = 3 days initially)

S = sludge accumulation rate (0.04 m^3/person-yr)

P = number of users

N = number of years between pumping of tank (yr)

Note: V_{req} must be greater than V_{init} and
V_{req} must be greater than V_{min}.

Final design of the septic tank should add 300 mm of free board above the required volume.

Sizing Pit Latrines

$V = 1.33 \times C \times P \times N$

$L = V/3$

Where:

V = volume (m^3)

C = sludge accumulation rate ($0.1\ m^3$/person-yr)

N = number of years between emptying of pit (yr)

L = length of pit (m) (pit 1m x 3m x L)

P = number of users

4.2.4 Criteria for Sewerage

Water Use

Water use should be greater than 25 lcd for small bore sewers.
Water use should be greater than 75 lcd for conventional sewers.

Minimum Pipe Velocities

The following velocities are required to maintain sediments in suspension:

Small bore sewers ----- 0.3 m/s
Conventional sewers --- 0.6 m/s

The evaluation of minimum pipe velocity should account for mean flow, peak flow, pipe slope, and pipe size. These factors have been considered in the foregoing criteria for water use.

Minimum Pipe Diameters

Small bore sewers: (septic tank to main) -------- 75 mm
(main) --------------------- 100 mm

Conventional sewers: (house to main) ------------ 100 mm
(main) -------------------- 150 mm

Minimum Pipe Slopes

Small bore sewers: (75 - 100 mm) ---------------- 1 in 150
(150 mm) --------------------- 1 in 250
(200 mm) --------------------- 1 in 300

Conventional sewers: (100 mm) ------------------- 1 in 40
(150 mm) ------------------- 1 in 60
(200 mm) ------------------- 1 in 250

4.2.5 Criteria for Wastewater Treatment and Disposal

Wastewater stabilization ponds are assumed for wastewater treatment and ultimate off-site disposal. The ponds should be designed with a minimum 30-day retention time and a depth of 2.0 meters. A preliminary estimate of the minimum area (m^2) requirements can be calculated by multiplying the total wastewater flow (m^3/day) by 30 days and dividing the result by 2 m. Allowance must be added to include area for dikes, access road, and a buffer zone. The design of an off-site wastewater disposal facility is beyond the scope of this report. The proposed detention time and depth provides for removal of a large portion of the settleable solids.

4.3 Methods for Soil Evaluation

4.3.1 Permeability

Permeability may be estimated by using Table 1 and knowledge of the soil types. This type of preliminary estimate should be confirmed by a percolation test. Percolation tests are empirical estimates of the soil suitability for subsurface disposal of wastewater. Such tests, however, do not give reliable estimates of long-term soil permeability to wastewater. Two different percolation test procedures are presented below.

Percolation Test No.1

Drill at least three, 150 mm diameter test holes, 1 to 5 m deep, across the proposed drainage field. Fill the holes with water and leave overnight to saturate the soil. Next day, fill the holes to a depth of 300 mm. Measure the water level at 30 minutes and at 90 minutes. Calculate the drop per hour. The soil has sufficient permeability if the percolation rate is greater than 15 mm/hr.

Percolation Test No. 2

Excavate a pit 1 m by 1 m in the vicinity of the proposed drainage field. Excavate to a depth of 1 m or to the soil horizon to be tested. At the bottom of the excavation, dig a hole 300 mm by 300 mm by 300 mm. Fill the hole with water and leave overnight to saturate the soil. Next day, refill the hole and measure the time for the water to percolate away completely. Calculate the average time in minutes for the water to drop 25 mm. The following table evaluates the soils suitability for on-site disposal.

Average Percolation Time Per 25 mm (minutes)	Suitability
1/4	Excellent
1	Very good
2	Good
5	Good
10	Fair
15	Fair
30	Fair to poor
60	Poor

4.3.2 Groundwater Conditions

The high groundwater elevation can be determined by placing three monitoring wells across the site. More than three wells may be necessary for larger sites or to check areas where high groundwater is suspected. Monitoring wells are small diameter perforated pipes placed in the soil at least three meters deep. Water levels in the wells are monitored throughout the wet season. The minimum depth to high groundwater is noted.

4.4 Methods of Wasteload Determination

The following sections illustrate how wasteloads may be calculated for preliminary design.

4.4.1 Population and Growth

Population estimates are based upon the site area, number of lots per hectare, and the number of people per lot.

Maximum Population

$$\text{Maximum Pop.} = A \times M \times P_m$$

Where:

A = area of the site (ha)

M = number of lots per hectare (M = 19 lots/ha)

P_m = maximum number of persons per lot (P_{max}=10)

Intermediate Population Projection

The population during any year is based upon the maximum population, the time to achieve the maximum population, and the initial population. A linear extrapolation is used.

$P_n = P_i + (P_m - P_i)(n/N)$

Where:

P_n = persons/lot in year n

P_i = persons/lot initially

P_m = maximum persons/lot

n = number of years site has been open for residence

N = number of years to achieve maximum persons/lot

Site Pop. (in year n) = $A \times M \times F_n \times P_n$

Where:

F_n = fraction of lots developed in year n

4.4.2 Wasteloads

Wasteload estimates are based upon water consumption and an estimate of the fraction of water consumed which becomes sullage.

Excreta

Excreta is assumed to be produced at a rate of 2 lcd.

$E_{lot} = P_n \times 2.0$

Where:

E_{lot} = excreta produced per house lot (l/day)

P_n = persons/lot in year n

E_{site} = (site pop.) x 2.0

E_{site} = excreta produced per site (l/day)

Sullage

Sullage is assumed to be 80 percent of the water consumed to be consistent with work done by others on Kenya (de Kruijff).

Lot Sullage = P_n x W x 0.8   Where:

W = water use rate (lcd)

P_n = persons/lot in year n

M = number of lots

Site Sullage = Lot Sullage x M

Total wastewater flow would be the sum of sullage and excreta. For the purposes of preliminary design, however, it can be estimated as the sullage flow.

4.5 Sanitation System Selection Algorithm

4.5.1 Data Required for Selection

The following set of questions requires answers in order to proceed through the selection algorithm:

1. Will the lots be accessible by truck?
2. What is the high annual groundwater elevation?
3. Is there area available for on-site disposal?
4. Does soil permeability permit on-site disposal?
5. What is the per capita water consumption rate?

To answer these questions, the following data must be gathered and interpreted for each question.

QUESTION NO. 1: Will the lots be accessible by truck?

A site plan showing roads, carriage ways, housing units and the approximate location of the water closets within the housing units should be available. A positive response to this question means that a truck can readily approach each house near its water closet.

QUESTION NO. 2: What is the high annual groundwater elevation?
The groundwater monitoring program described in section 4.3.2 should provide the answer to this question.

QUESTION NO. 3: Is there area for on-site disposal?
This question should be analyzed in two parts: is there area for on-site disposal in the housing plots and in the communal open space?

Housing lot on-site disposal

The following data are required:

1. Housing lot size (m^2)
2. Maximum housing size (m^2)
3. Reserve area (use 80 m^2)
4. Maximum number of persons per lot
5. Per capita water consumption rate (lcd).

Calculate the wastewater flow per lot (section 4.4.2). Calculate the on-site disposal area (section 4.2.3). If the lot size is greater than the sum of the house size, reserve area, and on-site disposal area, then Question No. 3 may be answered affirmatively.

Communal on-site disposal

The following data is required:

1. Site area (m^2)
2. Number of lots per hectare
3. Maximum number of persons per lot
4. Per capita water consumption rate (lcd)
5. Site communal open space (m^2).

Calculate the site wastewater flow (Section 4.4.2). Calculate the area required for on-site disposal of the site wastewater flow (Section 4.2.3). If the on-site disposal area required is less than half of the site communal open space, then Question No. 3 may be answered affirmatively.

QUESTION NO. 4: Does soil permeability permit on-site disposal?
Knowledge of the soil types and the results from percolation tests should be available. This information can be compared to the criteria presented in Section 4.3.1 to answer Question No. 4.

QUESTION NO. 5: What is the per capita water consumption rate?
An estimate of water consumption rates should be available based upon similar sites. It is assumed that consumption is 80 lcd for in-house water service and 25 lcd for communal water service.

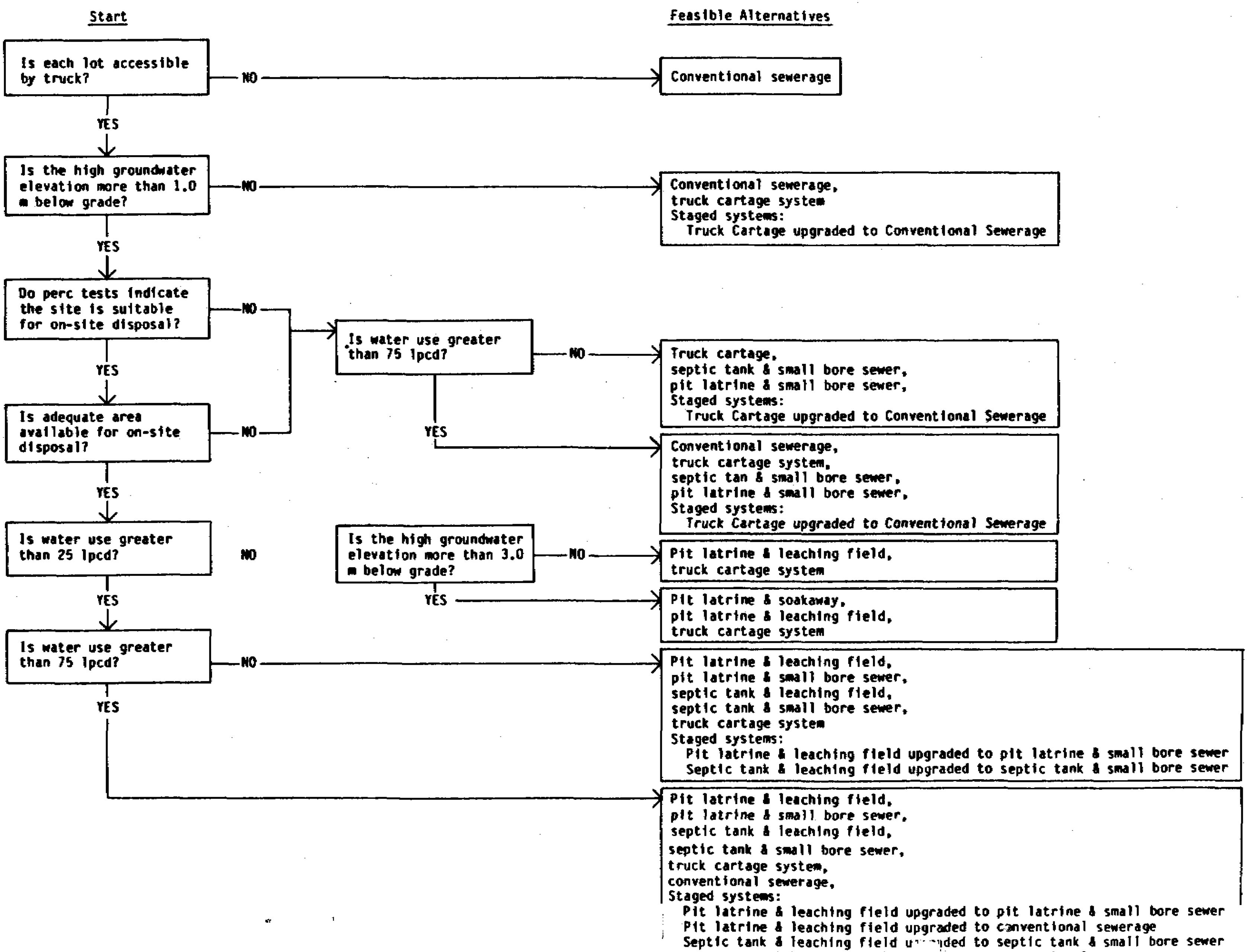
4.5.2 Selection Algorithm

Figure 8, on the following page, presents a selection algorithm applicable to the Kenyan Small Towns Shelter and Community Development Project. This algorithm does not consider costs. It considers only the technical feasibility of the various sanitation alternatives and incorporates assumptions stated previously about the housing sites, the availability of materials, and workmanship.

4.5.3 Technically Feasible Alternatives

The following example illustrates use of the selection algorithm. The data presented for this example are assumed to be representative of a typical housing project site.

FIGURE 8: SANITATION ALTERNATIVES SELECTION ALGORITHM



Selection Algorithm Preliminary Design Example

Assumptions: Water supply source located off the site
Water service inside each house
Water consumption = 80 lcd
Wastewater flow = 80% of water consumption
Maximum persons per lot = 10
Depth to high groundwater = 1.8 m
Permeability (k): k = 50 mm/day
Percolation test no. 2 = 2 min/25 mm
Limiting infiltration = 10 l/m^2-day
Number of lots/ha = 20
Lot size = 250 m^2
Maximum house area = 120 m^2
Reserve area around house = 80 m^2
Site area = 6 hectares
Communal open space = 1.5 hectares
Lots accessible by truck

Figure 9 illustrates, step by step, use of the selection algorithm based upon the foregoing assumptions.

STEP 1: Will the lots be accessible by truck?
The answer is "YES," move to step 2.
STEP 2: Is the depth to high groundwater greater than 1 m?
The answer is "YES" (1.8 m depth), move to step 3.
STEP 3: Does the soil permeability permit on-site disposal?
The answer is "YES" (k = 50 mm/day > 10 mm/day limit), move to step 4.
STEP 4: Is area available for on-site disposal?
This should be evaluated for housing lot and communal on-site disposal.

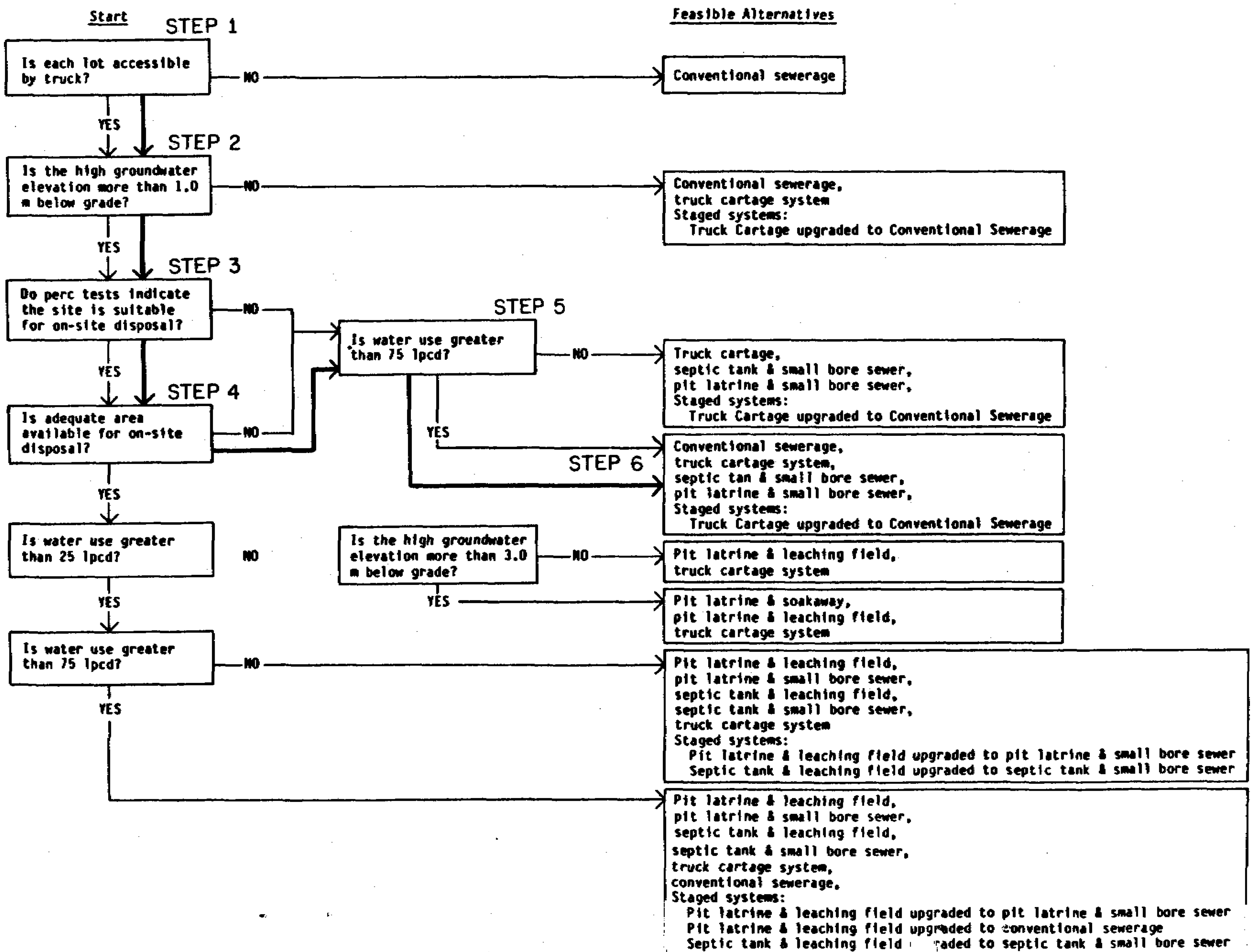


FIGURE 9: EXAMPLE USE OF SELECTION ALGORITHM

Housing lot on-site disposal

Wastewater flow/lot = (10 pers/lot)(80 lcd)(0.8)
= 640 l/day-lot

Infilt. area req. = (1.5)(640 l/day-lot)/(10 l/m^3-day)
= $96m^2$

The lot size (250 m^2) is less than the sum of house area, reserve area, and infiltration area (296 m^2). Thus, there is not adequate area for housing lot on-site disposal.

Communal on-site disposal

Site wastewater flow = (10 pers/lot)(80 lpcd)(0.8) x
(20 lots/ha)(6 ha)
= 76800 l/day

Disposal area required = (1.5) (76800 l/day)/(10 l/m^2-d)
= 11520 m^2
= 1.2 ha

The area required for disposal (1.2 ha) is larger than 50 percent of the communal open space (0.75 ha), which is the maximum allowable disposal area on communal land. Sufficient area, therefore, is unavailable for communal on-site disposal. Because area is available for neither housing on-lot disposal nor communal on-site disposal, proceed to Step 5.

STEP 5: Is water use greater than 75 lcd?
The answer is "YES," move to Step 6.

STEP: The following sanitation alternatives are technically feasible:
- conventional sewers
- truck and cartage system
- septic tank and small bore sewers
- pit latrine and small bore sewers.

The selection algorithm selects the technically feasible alternatives. The alternatives selected in the foregoing example are determined by the assumptions made. It is important to note that some of the assumptions are open to modification by planners (for example, number of lots per hectare) and will affect the selection of technically feasible sanitation alternatives.

4.6 Relative Cost Estimating

Once the technically feasible sanitation alternatives are identified, they can be compared based on capital, operation, and maintenance costs. It should be noted that each alternative represents a complete waste disposal scheme; that is, both sullage and excreta are included. The following sections identify major cost components for each sanitation technology and presents a preliminary approach to comparing alternatives based upon preliminary estimates for each component. It is recommended that actual current unit costs be used in the application of the approach presented.

4.6.1 Cost Criteria

Major cost components are presented for each sanitation alternative. A method for estimating the actual costs of the systems and a presentation of the economic analyses required to derive present values from future costs are beyond the scope of this report. All operation and maintenance (O&M) costs are expected to be incurred in the future at regular periods. A common design period (suggest 20 to 30 years) should be used for every alternative evaluated. Costs expected to be incurred within the design period should be brought to present value by standard economic analyses.

Pit latrine and soakaway

Capital costs: Pit latrine - - cost is based upon the pit volume (m^3)
Soakaway - - - cost is based upon the infiltration area required (m^2)

O&M costs: Pit latrine - - cost to periodically remove latrine contents, based on annual excreta volume (m^3)

Pit latrine and leaching field

Capital costs: Pit latrine - - cost is based upon the pit volume (m^3)
Leaching field- cost is based upon the length of drainage pipe required (m)

O&M costs: Pit latrine - - cost to periodically remove latrine contents, based on annual excreta volume (m^3)

Pit latrine and small bore sewer

Capital costs: Pit latrine - - cost is based upon the pit volume (m^3)
Sewer - - - - - cost is based upon pipe length (m)
Treatment - - - cost is based upon area require for waste stabilization pond (m^2)

O&M costs: Pit latrine - - cost to periodically remove latrine contents, based on annual excreta volume (m^3)
Sewer - - - - - cost for periodic flushing and repair
Treatment - - - labor cost for routine maintenance of waste stabilization pond

Septic tank and leaching field

Capital costs: Septic tank - - cost is based upon the tank volume (m^3)
Leaching field- cost is based upon the length of drainage pipe required (m)

O&M costs: Septic Tank - - cost to periodically remove sludge, based on annual sludge volume (m^3)

Septic tank and small bore sewer

Capital costs: Septic Tank - - cost is based upon the tank volume (m^3)
Sewer - - - - - cost is based upon pipe length (m)
Treatment - - - cost is based upon area required for waste stabilization pond (m^2)

O&M costs: Septic tank - - cost to periodically remove sludge, based on annual sludge volume (m^3)
Sewer - - - - - cost for periodic flushing and repair
Treatment - - - labor cost for routine maintenance of waste stabilization pond

Truck and cartage system

Capital costs: Vault - - - - - cost is based upon volume (m^3)

O&M costs: Pumping - - - - cost for periodic pumping of vault, based on wasteflow (l/day)

Conventional sewerage

Capital costs: Sewer - - - - - cost is based upon pipe length (m)

O&M costs: Sewer - - - - - cost for periodic flushing and repair

Treatment - - - labor cost for routine maintenance of waste stabilization pond, which would be slightly higher than separated sewage treatment due to the increased solids removal

Staged systems

Costs for staged systems are the present value of each component, as identified above.

4.6.2 Illustrative Unit Costs

Unit costs should be derived for each component based upon current contractor prices and local costs. Table 2 presents some hypothetical cost data for illustrative purposes. The following notes are intended as a guide for developing realistic unit costs.

Pit latrines

Unit capital costs for pit latrines should include costs for labor and all materials, for example, pit and superstructure components, blocks, cement, sand, fixtures, vent pipe, squatting plate, etc. The O&M cost for the pit latrine will depend upon size and design period for emptying. It is assumed that the cost for disposal of removed excreta is included in the excreta hauler's cost.

Soakaways

Unit capital costs for soakaways should include costs for labor and all materials, for example, grease or sand traps, plumbing, pipe, concrete block, stones, etc. The O&M costs for soakaways may be considered negligible.

Leaching fields

Unit capital costs for leaching fields should include costs for labor and all materials, for example, excavation, crushed stone, drainage pipe, distribution box, etc. O&M costs for properly designed leaching fields are considered to be negligible.

Septic tanks

Unit capital costs for septic tanks should include costs for labor and all materials, for example, excavation, cement, sand, reinforcement, pipes, fittings, pour-flush fixtures, etc. O&M costs for sludge pumping will depend on the design period for sludge pumping (usually two to three years). It is assumed that the cost for final disposal of the sludge is included in the sludge hauler's cost.

Small bore sewers

Unit capital costs for small bore sewers should include costs for labor and all materials, for example, excavation, bedding material, pipes, fittings, cleanouts, sand or grease traps, manholes, etc. O&M costs for small bore sewers should include the cost of periodic sewer flushing and repair and the installation of new manholes to repair clogged sections.

Conventional sewers

Unit capital costs for conventional sewers should include costs for labor and all materials, for example, excavation, bedding material, pipes, fittings, manholes, etc. O&M costs for conventional sewers should include the cost of periodic sewer flushing and repair.

Truck and cartage systems

Unit capital costs for vaults should include costs for labor and all materials, for example, excavation, blocks, cement sealing of vault, vent, plumbing to vault, etc. Capital costs also include trucks, disposal facility, and any necessary roadway improvements. O&M costs for these systems include the cost of periodic pumping. It is assumed that the cost for final disposal of the removed waste is included in the waste hauler's costs.

Treatment

Unit capital costs for waste treatment, by way of stabilization ponds, should include costs for labor and all materials to construct the treatment facility, including excavation, access roads, dikes, piping, concrete, fencing, land, etc. If the treatment facility is shared with another community, then the capital cost allocated to the housing project should be proportional to the amount of wasteflow contributed by the housing project. O&M costs should include maintenance of the treatment facility.

Table 2

Illustrative Unit Costs (Hypothetical)

Sanitation System Component	Unit Capital Costs	Present Value of Annual Unit O&M Costs[1]
Pit Latrine	600 Kshs/m^3	110 Kshs/m^3
Soakaway	20 Kshs/m^2	--------
Leaching Field	600 Kshs/m	--------
Septic Tank	700 Kshs/m^3	90 Kshs/m^3
Small Bore Sewer	700 Kshs/m	65 Kshs/m
Conventional Sewer	1200 Kshs/m	90 Kshs/m
Truck and Cartage	700 Kshs/m^3	300 Kshs/(l/day)
Treatment(separated sewage)	15 Kshs/m^2	3 Kshs/m^2
Treatment (conventional sewage)	15 Kshs/m^2	5 Kshs/m^2

[1]Based on 20 year life and 8 percent interest rate.

Cost Comparison Example

On the basis of the preliminary design example presented in Section 4.5.3, a comparison of the cost between conventional sewers and septic tanks with small bore sewers is presented using the unit costs in Table 2.

It is assumed that 750 meters of sewer pipe are required for sewering this site. The actual length usually would be estimated from a plan of the site layout. This length includes the pipe required to deliver waste flows to a treatment facility. The septic tank volume required for each lot is determined to be 3 m^3. The annual amount of sludge to be pumped from septic tanks is calculated as follows:

annual sludge = (0.04 m^3/pers-yr)(10 pers/lot)(120 lots)
= 48 m^3

The total waste flow from the site is calculated as 76800 l/day. The area required for waste treatment using a stabilization pond is calculated as follows:

treatment area = (76800 l/day)(30 days)/(2 m)(1000 l/m^3)
= 1152 m^2

The costs for a septic tank with small bore sewer system and a conventional sewer system are presented below.

Septic tank and small bore sewer (SSB)

Capital costs: Septic tank = (3m^3/lot)(120 lots)(700 Kshs/m^3)
= 252000 Kshs

Sewer = (750 m)(700 Kshs/m)
= 525000 Kshs

Treatment = (1152 m^2)(15 Kshs/m^2)
= 17280 Kshs

Present Value
of O&M costs: Septic tank = $(48\ m^3)(90\ Kshs/m^3)$
= 4320 Kshs
Sewer = (750 m)(65 Kshs/m)
= 48750 Kshs
Treatment = $(1152\ m^2)(3\ Kshs/m^2)$
= 3456 Kshs

Total cost = 850806 Kshs
Cost per lot = 7090 Kshs/lot

<u>Conventional sewerage (CS)</u>
Capital costs: Sewer = (750 m)(1200 Kshs/m)
Treatment = 900000 Kshs
= $(1152\ m^2)(15\ Kshs/m^2)$
= 17280 Kshs
Present Value
of O&M costs: Sewer = (750 m)(90 Kshs/m)
= 67500 Kshs
Treatment = $(1152\ m^2)(5\ Kshs/m^2)$
= 5760 Kshs

Total cost = 990540 Kshs
Cost per lot = 8255 Kshs/lot

Thus, for this example site and these example unit costs, septic tanks with small bore sewers (7,090 Kshs/lot) would be less expensive than conventional sewerage (8,255 Kshs/lot) on a present-worth basis. Similar analyses may be prepared for other feasible alternatives.

4.7 Final Selection and Design of Sanitation Alternatives

Once the technically feasible sanitation alternatives and costs for a site have been determined, the planner must select between the alternatives. Preliminary cost analyses, as presented above, can be used to evaluate the

REFERENCES

The following is the list of principal references used in preparing this report and those deemed most useful for further detailed evaluation of alternatives to conventional sewers.

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