Appropriate Technology for Water Supply and Sanitation, Volume 2: A Planner's Guide

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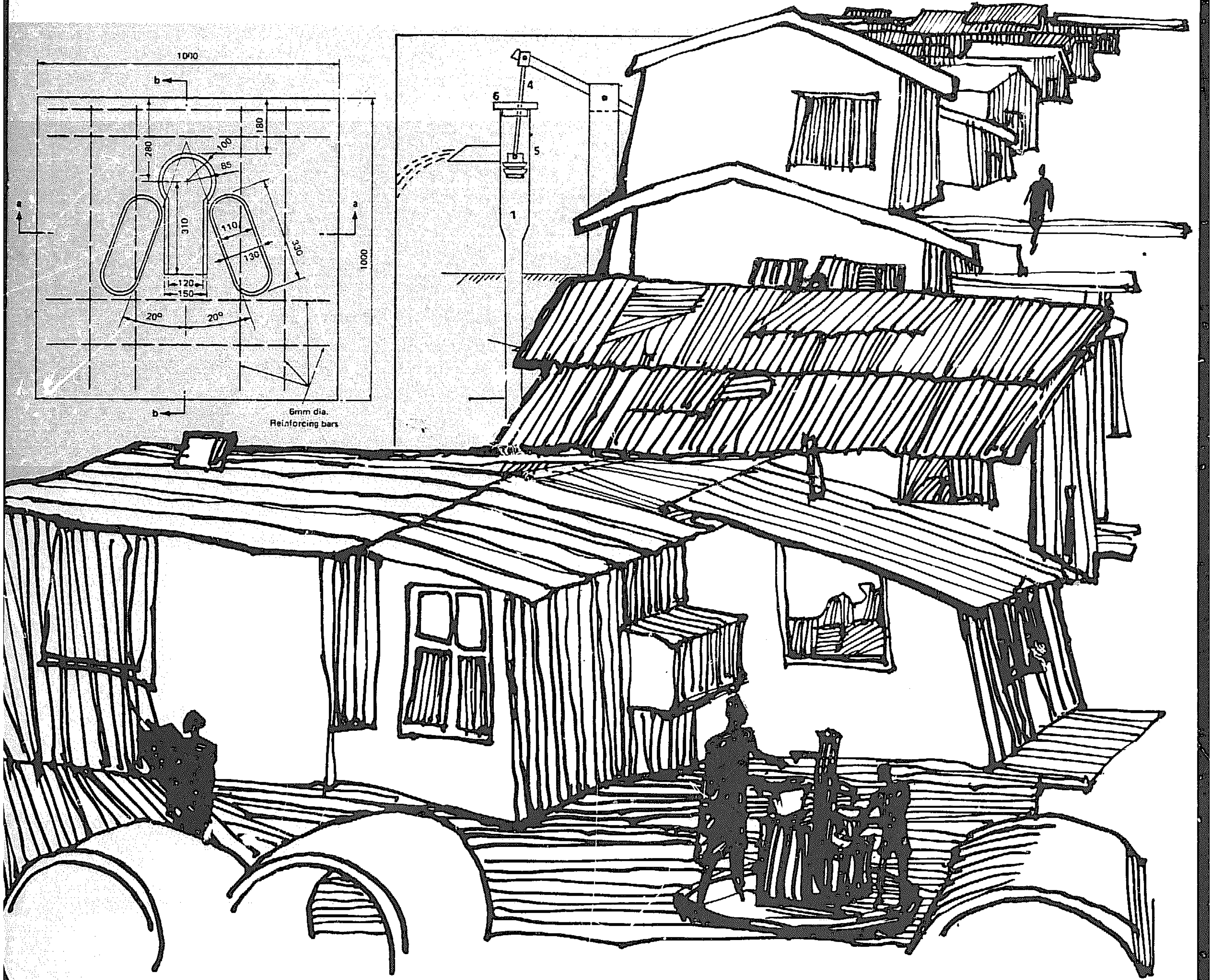

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A Contribution to the International Drinking Water Supply and Sanitation Decade

2

Volume 2

APPROPRIATE TECHNOLOGY FOR WATER SUPPLY AND SANITATION

A PLANNER'S GUIDE

Transportation, Water and Telecommunications Department

The World Bank

December 1980

ABSTRACT

This report provides information and instructions on how to design and implement appropriate technology projects based on the findings reported in Volume 1, *Technical and Economic Options*. It provides guidelines and design tools for the engineers and sanitarians responsible for planning and implementing sanitation projects.

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ACRONYMS USED IN THIS REPORT

AIC	-	Average incremental cost
BARC	-	Beltsville Agricultural Research Center (U.S. Department of Agriculture, Beltsville, Maryland, USA)
BOD	-	Biochemical oxygen demand
BOD_5	-	BOD by the standard test
DVC	-	Double-vault composting (as in "DVC toilets")
gcd	-	Grams per capita daily
lcd	-	Liters per capita daily
PF	-	Pour-flush (as in "PF toilets")
PVC	-	Polyvinyl chloride
ROEC	-	Reed Odorless Earth Closet
VIDP	-	Ventilated improved double-pit (as in "VIDP latrines")
VIP	-	Ventilated improved pit (as in "VIP latrines"

PREFACE

In 1976 the World Bank undertook a research project on appropriate technology for water supply and waste disposal in developing countries. Emphasis was directed toward sanitation and reclamation technologies, particularly as they are affected by water service levels and by ability and willingness to pay on the part of the project beneficiaries. In addition to the technical and economic factors, assessments were made of environmental, public health, institutional, and social constraints. The findings of the World Bank research project and other parallel research activities in the field of low-cost water supply and sanitation are presented in the series of publications entitled *Appropriate Technology for Water Supply and Sanitation*, of which this report is volume 2. Other volumes in this series are as follows:

[vol. 1] - *Technical and Economic Options*, by John M. Kalbermatten, DeAnne S. Julius, and Charles G. Gunnerson [a condensation of *Appropriate Sanitation Alternatives: A Technical and Economic Appraisal*, forthcoming from Johns Hopkins University Press]

[vol. 1a] - *A Summary of Technical and Economic Options*

[vol. 3] - *Health Aspects of Excreta and Sullage Management--A State-of-the-Art Review*, by Richard G. Feachem, David J. Bradley, Hemda Garelick, and D. Duncan Mara [a condensation of *Sanitation and Disease: Health Aspects of Excreta and Wastewater Management*, forthcoming from Johns Hopkins University Press]

[vol. 4] - *Low-Cost Technology Options for Sanitation--A State-of-the-Art Review and Annotated Bibliography*, by Witold Rybczynski, Chongrak Polprasert, and Michael McGarry [available, as a joint publication, from the International Development Research Centre, Ottawa, Ontario, Canada]

[vol. 5] - *Sociocultural Aspects of Water Supply and Excreta Disposal*, by M. Elmendorf and P. Buckles

[vol. 6] - *Country Studies in Sanitation Altenatives*, by Richard A. Kuhlthau (ed.)

[vol. 7] - *Alternative Sanitation Technologies for Urban Areas in Africa*, by Richard G. Feachem, D. Duncan Mara, and Kenneth O. Iwugo

[vol. 8] - *Seven Case Studies of Rural and Urban Fringe Areas in Latin America*, by Mary Elmendorf (ed.)

[vol. 9] - Design of Low-Cost Water Distribution Systems, Section 1 by Donald T. Lauria, Peter J. Kolsky, and Richard N. Middleton; Section 2 by Keith Demke and Donald T. Lauria; and Section 3 by Paul V. Herbert.

[vol. 10] - Night-soil Composting, by Hillel I. Shuval, Charles G. Gunnerson, and DeAnne S. Julius

[vol. 11] - A Sanitation Field Manual, by John M. Kalbermatten, DeAnne S. Julius, Charles G. Gunnerson, and D. Duncan Mara

[vol. 12] - Low-Cost Water Distribution--A Field Manual, by Charles D. Spangler

The more complete, book versions of this report and volumes 1 and 3 are forthcoming -- under the series title "World Bank Studies in Water Supply and Sanitation" -- from the Johns Hopkins University Press (Baltimore and London).

Additional volumes and occasional papers will be published as ongoing research is completed. With the exception of volume 4, all reports may be obtained from the World Bank's Publications Unit.

It is the purpose of this manual to provide early dissemination of research results to field workers, to summarize selected portions of the other publications that are needed for sanitation program planning, and to describe engineering details of alternative sanitation technologies and the means by which they can be upgraded. While the design of water supply systems is not discussed, information on water service levels corresponding to sanitation options is included because water use is a determinant of wastewater disposal requirements. The guidelines, procedures, and technologies contained in this volume are based upon World Bank studies in nineteen developing and industrial countries where local specialists conducted or contributed to the research. Both the research and its application continue to be evolved by the Bank and others throughout the world. Future supplements will present improvements in some technologies, such as biogas; information on others, such as marine disposals, combined sewers, water-saving plumbing fixtures, and small-bore sewer design and operation; and more precise estimates of materials and construction requirements on both per capita and population-density bases.

This manual is intended both for professionally trained project engineers and scientists and for technicians and field workers who are familiar with the geographical and cultural conditions of the project areas to which they are assigned. The reason for this emphasis is clear: it is upon the observations, interpretations, and communications of staff in the field that the ultimate success of sanitation programs depends; technical and economic analyses must incorporate recommendations from knowledgeable field specialists.

The findings and recommendations of this report are based on surveys of relevant literature (volumes 6 and 4), an evaluation of sociocultural aspects (volume 5), detailed field studies (volumes 6, 7, 8, and 9), and the personal observations, experience, and advice of colleagues in the World Bank and other institutions. Because the list of contributors is so large, only a few can be mentioned. We wish to acknowledge in particular the support given to this project by Mr. Yves Rovani, Director, Energy Department, and the valuable review and direction provided by the Bank staff serving on the Steering Committee for the project: Messrs. E. Jaycox, A. Bruestle, W. Cosgrove, F. Hotes, D. Keare, J. Linn, R. Middleton, R. Overby, A. Stone, and C. Weiss; Messrs. M. McGarry and W. Rybczinski were generous in their advice on specific issues. The contributions of consultants conducting field studies and providing specialized reports are acknowledged in the volumes to which they have contributed.

Special thanks are due to Messrs. R. Feachem and D. Bradley, who have generously contributed help and advice and allowed us to abstract and quote from some of their own publications.

The reports could not have been produced without the dedication and cooperation of the secretarial staff, Margaret Koilpillai, Julia Ben Ezra, and Susan Purcell, and the editorial and production assistance of research assistants Sylvie Brebion and David Dalmat. Their work is gratefully acknowledged.

John M. Kalbermatten
DeAnne S. Julius
Charles G. Gunnerson
D. Duncan Mara

PART ONE

SOCIOECONOMIC ASPECTS OF SANITATION PROGRAM PLANNING

CHAPTER I

INTRODUCTION

A convenient supply of safe water and the sanitary disposal of human wastes are essential, although not the only, ingredients of a healthy, productive life. 1/ Water that is not safe for human consumption can spread disease; water that is not conveniently located results in the loss of productive time and energy by the water carrier--usually women or children; and inadequate facilities for excreta disposal reduce the potential benefits of a safe water supply by transmitting pathogens from infected to healthy persons. Over fifty infections can be transferred from a diseased person to a healthy one by various direct or indirect routes involving excreta.

Invariably it is the poor who suffer the most from the absence of safe water and sanitation, because they lack not only the means to provide for such facilities but also information on how to minimize the ill effects of the insanitary conditions in which they live. As a result, the debilitating effects of insanitary living conditions lower the productive potential of the very people who can least afford it.

Dimensions of the Problem

One of the fundamental problems in any attempt to provide the necessary sanitation services is their cost. Very general estimates based on existing per capita costs indicate that up to $60 billion would be required to provide water supply for everyone and from $300 to $600 billion would be needed for sewerage. 2/ Per capita investment costs for the latter range from $150 to $650, which is totally beyond the ability of the intended beneficiaries to pay. It should be remembered that some one billion of these unserved people have per capita incomes of less than US$200 per year, with more than half of those below US$100 per year.

In industrialized countries, the standard solution for the sanitary disposal of human excreta is waterborne sewerage. Users and responsible agencies have come to view the flush toilet as the absolutely essential part of an adequate solution to the problem of excreta disposal. This method, however, was designed to maximize user convenience rather than health benefits. In fact, conventional sewerage is the result of slow development over decades, even centuries, from the pit latrine to the flush toilet, and the present standard of convenience has been achieved at substantial economic and environmental costs.

The problem facing developing countries is a familiar one: high expectations coupled with limited resources. Decision-makers are asked to achieve the standards of convenience observed in industrialized countries.

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1. Much of this chapter is taken from chapters 1 and 2 of volume I of this report series.

2. All dollar figures in this report are 1978 U.S. dollars.

Given the backlog in service, the massive size of sewerage investments and the demands on financial resources by other sectors, they do not have the funds to realize this goal.

At the present time the first priority of excreta disposal programs in developing countries should be the improvement of human health; that is, the accomplishment of a significant reduction in the transmission of excreta-related diseases. This health objective can be fully achieved by sanitation technologies which are much cheaper than sewerage.

The Constraints

The primary constraints to the successful provision of sanitation facilities in developing countries are the lack of funds, the lack of trained personnel, and the lack of knowledge about acceptable alternative technologies. Where high cost systems developed in industrialized countries have been used to solve waste disposal problems in developing countries, access to the facilities has been limited to the higher income groups, who are the only ones able to afford them. Little official attention has been paid to the use of low-cost sanitation facilities to provide health benefits to the majority of the population. This situation exists because officials and engineers in developing and developed countries alike are not trained to consider or design alternative sanitation systems, nor to evaluate the impact of these alternatives on health. Waterborne sewerage was designed to satisfy convenience and local environmental, rather than health, requirements. The lesson commonly (but erroneously) drawn from the historical development of sanitation technology is that the many less costly alternatives formerly used should be abandoned rather than improved. Therefore, few serious attempts have been made to design and implement satisfactory low-cost sanitation technologies. The implementation of such alternatives is complicated by the need to provide for community participation in both the design and operating stages of the projects. Few engineers are aware of the need to consider the sociocultural aspects of excreta disposal, and fewer still are competent to work with a community to determine the technology most compatible with its needs and resources.

Given these constraints, it is not surprising that sanitation service levels in developing countries have remained low. A major effort is needed to identify and develop alternative sanitation technologies appropriate to local conditions in developing countries and designed to improve health rather than raise standards of user convenience. Clearly the solutions must be affordable to the user and reflect community preferences if they are to find acceptance.

Incremental Sanitation

An examination of how conventional waterborne sewerage came about reveals three facts very clearly. First, excreta disposal went through many stages before sewerage. Second, existing systems were improved and new solutions devised whenever the old solution was no longer satisfactory. Third, improvements were implemented over a long period of time and at substantial cost. Sewerage was not a grand design implemented in one giant step, but the end result of a long series of progressively more sophisticated solutions.

For example, the collection of night soil from bucket latrines in eighteenth century London was a step toward reducing gross urban pollution. This was followed by piped water supplies and the development of combined sewerage, then to separate sanitary sewerage, and eventually to sewage treatment prior to river discharge. This particular series of improvements spanned over 100 years--a long time frame necessitated by historical constraints in science and technology. Present levels of knowledge enable sanitation planners to select from a wider range of options and to design a sequence of incremental sanitation improvements. The choice of proceeding with sequential improvements is the user's. He also decides the time frame over which improvements are to be made and is thus able to provide higher levels of convenience, keeping pace with increasing income. Most importantly, a user can start with a basic low-cost facility without the need to wait for greater income, knowing that he has a choice to provide for greater convenience if he has the funds and wishes to do so at some future date.

Sanitation Program Planning

Sanitation program planning is the process by which the most appropriate sanitation technology for a given community is identified, designed, and implemented. The most appropriate technology is defined as that which provides the most socially and environmentally acceptable level of service at the least economic cost.

The process of selecting the appropriate technology begins with an examination of all of the alternatives available for improving sanitation; these are described in part II of this manual. There will usually be some technologies that can be readily excluded for technical or social reasons. For example, septic tanks requiring large drainfields would be technically inappropriate for a site with a high population density. Similarly, a composting latrine would be socially inappropriate for people who have strong cultural objections to the sight or handling of excreta. Once these exclusions have been made, cost estimates are prepared for the remaining technologies. These estimates should reflect real resource cost to the economy, and, as described in chapter 4, this may involve making adjustments in market prices to counteract economic distortions or to reflect development goals such as employment creation. Since the benefits of various sanitation technologies cannot be quantified, the health specialist must identify those environmental factors in the community that act as disease vehicles and recommend improvements that can help prevent disease transmission. The final step in identifying the most appropriate sanitation technology rests with the intended beneficiaries. Those alternatives that have survived technical, social, economic, and health tests are presented to the community with their attached financial price tags, and the users themselves decide what they are willing to pay for. A technology selection algorithm that incorporates economic, social, health, and technical criteria is presented in chapter 6.

Figure 1-1 shows how the various checks are actually coordinated in practice. The checks themselves, of course, are interrelated. A technology may fail technically if the users' social preferences militate against its proper maintenance. The economic cost of a system is heavily dependent upon social factors, such as labor productivity, as well as technical parameters.

Because it is operationally difficult to employ simultaneous (or even iterative) decision processes, however, a step-by-step approach with feedback across disciplines is suggested.

For simplicity it is assumed that separate individuals or groups are responsible for each part, although in practice responsibilities may overlap. In step 1 each specialist collects the information necessary to make his respective exclusion tests. For the engineer, public health specialist, and behavioral scientist 1/ this data collection would usually take place in the community to be served. The economist would talk with both government and municipal officials to obtain the information necessary to calculate shadow rates and to obtain information on the financial resources likely to be available. The behavioral scientist would consult with and survey the potential user and community groups. Then the engineer and sociologist apply the information they have collected to arrive at preliminary lists of technically and socially feasible alternatives. The public health specialist relates the most important health problems to any relevant environmental factors involving water and/or excreta. In the third step the economist prepares economic cost estimates for those technologies that have passed the technical and social tests, and selects the least-cost alternative for each technology option. As the fourth step the engineer prepares final designs for these remaining choices. At this stage the social information collected in step 1 should be used to determine the siting of the latrine on the plot, the size of the superstructure, the materials to be used for the seat or slab, and other details that may have low technical and economic impact but make a major difference in the way the technology is accepted and used in the community. The designs should also incorporate features necessary to maximize the health benefits from each technology. Final designs are turned over to the economist in the fifth step so that financial costs can be determined, including how much the user would be asked to pay for construction and maintenance of each alternative. The last step is for the behavioral scientist to present and explain the alternatives, their financial costs, and their future upgrading possibilities to the community for final selection. The form that this community participation takes will vary greatly from country to country, but the important elements are discussed in chapter 3.

As part of the sanitation planning process, the existing or likely future pattern of domestic water use should be ascertained so that the most appropriate method of sullage disposal can be selected. This is particularly important in the case of properties with a multiple tap level of water supply service, as the large wastewater flows may, according to conventional wisdom, preclude the consideration of technologies other than sewerage or, in low-density areas, septic tanks with soakaways. It is not necessary, however, either for reasons of health or user convenience, for domestic water consump-

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1. The term "behavioral scientist" is used to describe a person skilled in assessing community needs, preferences, and processes. The person's training may be in anthropology, communications, geography, sociology, or psychology, or it may come from a wide variety of education and experience.

tion to exceed 100 liters per capita daily (lcd). 1/ The use of low-volume cistern-flush toilets and various simple and inexpensive devices for reducing the rate of water flow from taps and showerheads can achieve very substantial savings in water consumption without any decrease in user convenience or requiring any change in personal washing habits. These savings can be as high as 75 percent in high-water-pressure areas and 30-50 percent in low-pressure areas. If wastewater flows can be reduced by these means, then the options for sanitation facilities are much broader than only conventional sewerage. In addition, separation of toilet wastes from other wastewater by simple modifications in household plumbing coupled with improved designs of septic tanks (see chapter 8) may make nonsewered options more widely feasible.

The framework suggested in this chapter for the identification of the most appropriate technology is probably more time intensive than that of traditional feasibility analysis. It also requires the recruitment of staff in other disciplines, such as behavioral scientists. In addition, the concept of incremental sanitation requires municipal activity in sanitation programs to be spread over a considerably longer time frame because the user has the option of whether and when to proceed to the next higher level of convenience. Yet we believe that the planning format discussed above has a far greater chance of achieving operational success because the most appropriate sanitation technology is drawn from a wider range of alternatives, imposes the least cost burden on the economy, maximizes the health benefits obtainable, and is selected after extensive interaction with the intended beneficiaries. Because incremental sanitation systems are so much less expensive than sewerage (both in initial investment and total discounted cost), many more people can be provided with satisfactory excreta disposal facilities for the same amount of money, and these facilities can be upgraded as more money becomes available in the future. Given the huge service backlog and the severe investment capital constraints in developing countries, incremental sanitation may be the only, as well as the best, way to meet the sanitation goals of the International Drinking Water Supply and Sanitation Decade.

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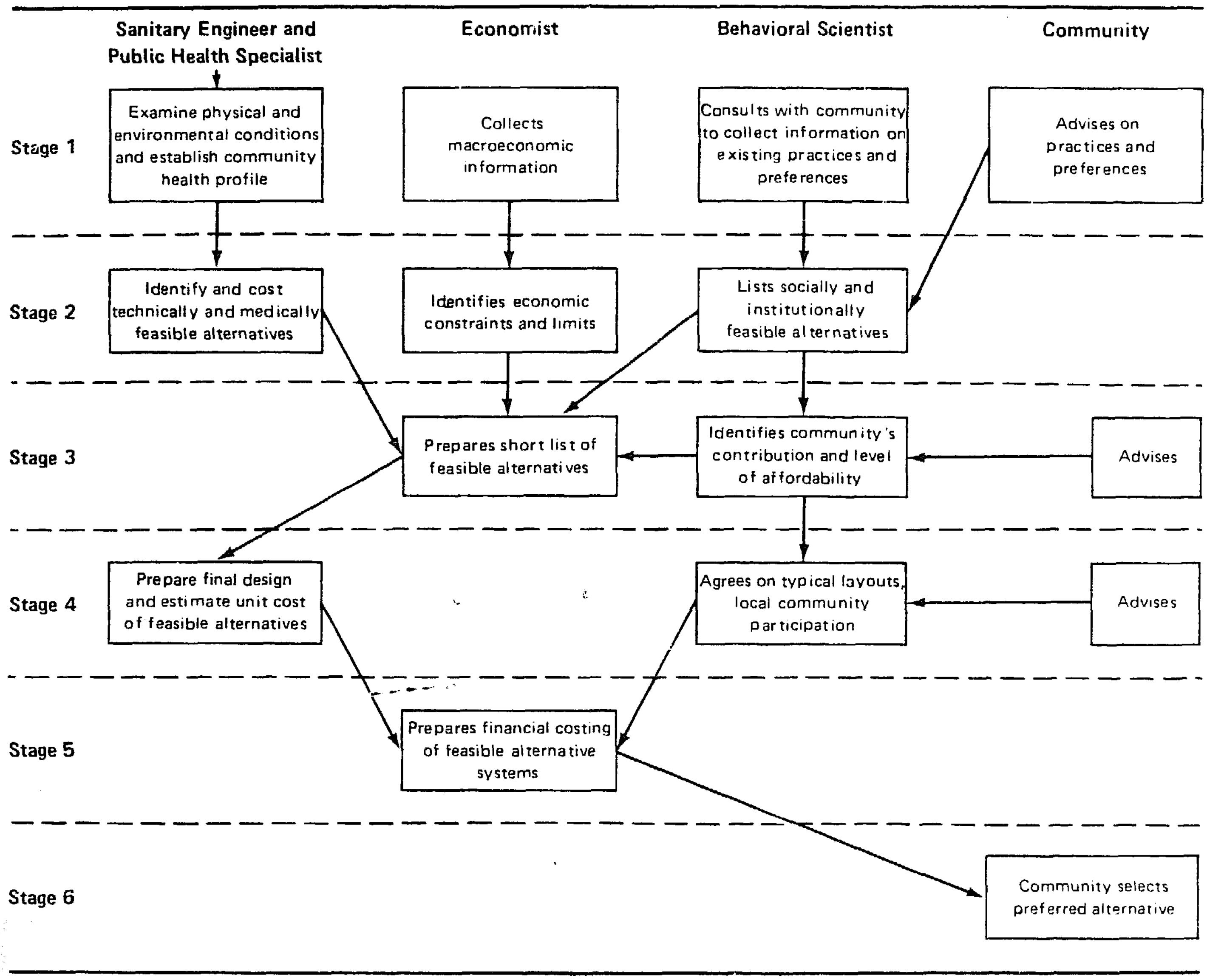
1. Where water has to be carried, 20 liters per capita daily is considered a minimum acceptable level. With closer standpipe spacing and yard hydrants, consumption rises typically to 50 liters per capita daily and, with house connections, 100 liters per capita daily.

Figure 1–1. Recommended Structure of Feasibility Studies for Sanitation Program Planning



CHAPTER 2

HEALTH ASPECTS OF SANITATION

Improved health is normally considered one of the principal benefits of improved sanitation.[1] Excreta contain a wide variety of human pathogens (Tables 2-1, 2-2, and 2-3), and the removal of these pathogens from the immediate environment, which is achieved by proper sanitation, can have a dramatic impact on community health. Prior or concurrent improvements in water supply and solid waste collection services and a vigorous and sustained campaign of community education in hygiene are ordinarily required, however, before all the health benefits of a sanitation improvement program can be realized.

In this chapter a recently developed environmental classification of excreta-related infections is presented and the likely health benefits of sanitation improvements are discussed. Particular emphasis is placed on how they relate to children, who are in many ways the most vulnerable to excreta-related infections.

Excreted Infections

Excreta are related to human disease in two ways. First, the agents of many important infections escape from the body in the excreta and eventually reach other people. These are called the excreted infections. In some cases the reservoir of infection is almost entirely in animals other than man. These are not considered here because such infections cannot be controlled through changes in human excreta disposal practices. A number of infections for which both man and other animals serve as a reservoir are included, however.

The second way in which excreta relate to human disease is where their disposal encourages the breeding of insects. These insects may be a nuisance in themselves (flies, cockroaches, mosquitoes); they may transmit excreted pathogens mechanically, either on their bodies or in their intestinal tracts (cockroaches and flies); or they may be vectors for pathogens that circulate in the blood (mosquitoes). Where flies or cockroaches are acting as vehicles for the transmission of excreted pathogens, this represents a particular case of the many ways in which excreted pathogens may pass from anus to mouth.

In considering the transmission of excreted infections, the distinction between the state of being infected and the state of being diseased must be kept in mind. Very often the most important section of the population involved in transmitting an infection shows little or no sign

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[1] Much of this chapter is taken directly from volume 3 of this report series.

Table 2-1. Viral, bacterial and protozoan pathogens found in excreta

Biological group	Organism	Disease	Reservoir
Viruses	Polio virus	Poliomyelitis	Man
	ECHO virus	Various	Man
	Cocksackie virus	Various	Man
	Hepatitus A virus	Infectious hepatitis	Man
	Rotavirus	Gastroenteritis in children	
Bacteria	*Salmonella typhi*	Typhoid fever	Man
	Salmonella paratyphi	Paratyphoid fever	Man
	Other salmonellae	Food poisoning	Man and animals
	Shigella species	Bacillary dysentery	Man
	Vibrio cholerae	Cholera	Man
	Other vibrios	Diarrhea	Man
	Pathogenic *E. coli*	Gastroenteritis	Man
	Yersinia species	Yersinosis	Animals and man
	Campylobacter species	Diarrhea in children	Animals and man
Protozoa	*Entamoebic histolytica*	Amoebic dysentery and liver abscess	Man
	Giardia lamblia	Diarrhea and malabsorption	Man
	Balantidium coli	Mild diarrhea	Man and animals

Note: With all diseases listed, a symptomless human carrier state exists.

Table 2-2. Helminthic pathogens found in excreta

Disease	Common Name	Pathogen	Transmission	Distribution
Ascariasis	Round worm	Ascaris lumbricoides	man - soil - man	worldwide
Clonorchiasis	Chinese liver fluke	Clonorchis sinensis	animal or man-aquatic snail-fish - man	S.E. Asia
Opisthorchiasis	Cat liver fluke	Opisthorchis felineus O. viverrini	animal - aquatic snail - fish - man	USSR Thailand
Diphyllobothriasis	Fish tapeworm	Diphyllobothrium latum	man or animal - copepod - fish - man	widely distributed foci, mainly in temperate regions
Enterobiasis	Pinworm	Enterobius vermicularis	man - man	worldwide
Fascioliasis	Sheep liver fluke	Fasciola hepatica	sheep - aquatic snail - aquatic vegetation - man	worldwide in sheep and cattle raising areas
Fasciolopsiasis	Giant intestinal fluke	Fasciolopsis buski	man or pig - aquatic snail - aquatic vegetation - man	S.E. Asia mainly China
Gastrodiscoidiasis		Gastrodiscoides hominis	pig - aquatic snail - aquatic vegetation - man	India, Bangladesh, Vietnam, Philippines
Heterophyiasis		Heterophyes heterophyes	dog or cat - brackish water snail - brackish water fish - man	Middle East, southern Europe, Asia
Hookworm	Hookworm	Ancylostoma duodenale, Necator americanus	man - soil - man	mainly in warm wet climates

Table 2-2 (Continued)

Disease	Common Name	Pathogen	Transmission	Distribution
Hymenolepiasis	Dwarf tapeworm	Hymenolepis species	man or rodent - man	worldwide
Metagonimiasis		Metagonimus yokogawai	dog or cat - aquatic snail - freshwater fish - man	Japan, Korea, China, Taiwan, Siberia
Paragonimiasis	Lung fluke	Paragonimus westermani	pig, man, dog, cat or other animal - aquatic snail - crab or crayfish - man	S.E. Asia, scattered foci in Africa and S. America
Schistosomiasis	Bilharzia	Schistosoma haematobium	man - aquatic snail - man	Africa, Middle East, India
		S. mansoni	man - aquatic snail - man	Africa, Arabia, Latin America
		S. japonicum	animals and man - snail - man	S.E. Asia
Strongyloidiasis	Threadworm	Strongyloides stercoralis	man-man (possibly dog - man)	mainly in warm wet climates
Taeniasis	Beef tapeworm	Taenia saginata	man - cow - man	worldwide
	Pork tapeworm	Taenia solium	man - pig - man or man - man	worldwide
Trichuriasis	Whipworm	Trichuris trichiura	man - soil - man	worldwide

Table 2–3. Environmental Classification of Excreted Infections

Category	Epidemiological feature	Infection	Dominant transmission focus	Major control measure
I	Nonlatent, low infective dose	Enterobiasis Enteroviral infections Hymenolepiasis Amoebiasis Giardiasis Balantidiasis	Personal Domestic	Domestic water supply Health education Improved housing Provision of toilets
II	Non–latent medium or high infective dose, moderately persistent and able to multiply	Typhoid Salmonellosis Shigellosis Cholera Path. *Escherichia coli* Yersiniosis *Campylobacter* infection	Personal Domestic Water Crop	Domestic water supply Health education Improved housing Provision of toilets Treatment prior to discharge or reuse
III	Latent and persistent with no intermediate host	Ascariasis Trichuriasis Hookworm	Yard Field Crop	Provision of toilets Treatment of excreta prior to land application
IV	Latent and persistent with cow or pig intermediate host	Taeniasis	Yard Field Fodder	Provision of toilets Treatment of excreta prior to land application Cooking, meat inspection
V	Latent and persistent with aquatic intermediate host (s)	Clonorchiasis Diphyllobothriasis Fascioliasis Fasciolopsiasis Gastrodiscoidiasis Heterophyiasis Metagonimiasis Paragonimiasis Schistosomiasis	Water	Provision of toilets Treatment of excreta prior to discharge Control of animal reservoirs Cooking
VI	Excreta-related insect vectors	Bancroftian filariasis (transmitted by *Culex pipiens*), and all the infections listed in I–V for which flies and cockroaches can be vectors	Various fecally contaminated sites in which insects breed	Identification and elimination of suitable breeding sites

Source: Feachem and others, *Sanitation and Disease*.

of disease; conversely, individuals with advanced states of disease may be of little or no importance in transmission. A good example occurs in schistosomiasis, where as much as 80 percent of the total egg output in feces and urine reaching water from a human population may be produced by children in the 5- to 15-year-old group; many of these children will show minimal signs of disease. Conversely, adults with terminal disease conditions may produce few or no viable eggs.

If an excreted infection is to spread, an infective dose of the relevant agent has to pass from the excreta of a case, carrier, or reservoir of infection to the mouth or some other portal of entry of a susceptible person. Spread will depend upon the numbers of pathogens excreted, upon how these numbers change during the particular transmission route or life cycle, and upon the dose required to infect a new individual. Infective dose is in turn related to the susceptibility of the new host. Three key factors govern the probability that, for a given transmission route, the excreted pathogens from one host will form an infective dose for another. These are latency, persistence, and multiplication. Diagrammatically, we can represent the concepts thus:

$$\text{EXCRETED LOAD} \longrightarrow \left(\begin{array}{c} \text{latency} \\ \\ \text{persistence} \\ \\ \text{multiplication} \end{array} \right) \longrightarrow \text{INFECTIVE DOSE}$$

These concepts are discussed in turn.

Excreted load. There is wide variation in the concentration of pathogens passed by an infected person. For instance, a person infected by a small number of nematode worms may be passing a few eggs per gram of feces, whereas a cholera carrier may be excreting more than 10^6 *Vibrio cholerae* per gram, and a patient may pass 10^{13} vibrios per day.

Latency. Latency is the interval between the excretion of a pathogen and its becoming infective to a new host. Some organisms, including all excreted viruses, bacteria, and protozoa, have no latent period and are immediately infectious when the excreta are passed. The requirements for the safe disposal of excreta containing these agents are far more stringent than for those helminthic infections in which there is a prolonged latent period.

Among the helminthic infections only three have eggs or larvae that may be immediately infectious to man when passed in the feces. These are *Enterobius vermicularis*, *Hymenolepis nana*, and, sometimes, *Strongyloides stercoralis*. The remaining excreted helminths all have a distinct latent period, either because the eggs must develop into an infectious stage in the physical environment outside the body or because the parasite has one or more intermediate hosts through which it must pass in order to complete its life cycle.

Persistence. Persistence, or survival, of the pathogen in the environment is a measure of how quickly it dies after it has been passed in the feces. It is the single property most indicative of the fecal hazard in that a very persistent pathogen will create a risk throughout most treatment processes and during the reuse of excreta.

While it is easy to measure persistence or viability of pathogenic organisms by laboratory methods, to interpret such results it is necessary to know how many are being shed in the excreta (which is relatively easy to determine) and the infective doses for man (which is extremely difficult to discover).

Multiplication. Under some conditions certain pathogens will multiply in the environment. Thus, originally low numbers can be multiplied to produce a potentially infective dose. Multiplication can take the form of reproduction by bacteria in a favorable environment (e.g., Salmonella on food), or of the multiplication by trematode worms in their molluscan intermediate hosts.

Among the helminths transmitted by excreta, all the trematodes infecting man undergo multiplication in aquatic snails. This introduces a prolonged latent period of a month or more while development is taking place in the snail, followed by an output of up to several thousand larvae into the environment for each egg that reached a snail.

Host Response. This is important in determining the result of an individual receiving a given dose of an infectious agent. In particular, acquired immunity and the relation of age to pathology are important for predicting the effects of sanitation improvements. In general the balance between exposure to infection and a host's response to it will determine the pattern of excreta-related disease. If transmission, creating exposure to a particular infection, is low, then few people will have encountered the infection; most will be susceptible. If a sudden increase in transmission of the disease occurs, it will affect all age groups in epidemic form. Improvements in sanitation will have a big effect under these circumstances by reducing the likelihood of an epidemic and, should one occur, its magnitude. By contrast, if transmission is very high, all the people will be repeatedly exposed to infection and first acquire it in childhood. Subsequent exposures may be without effect if long-lasting immunity is acquired from the first attack. Alternatively, immunity may be cumulative from a series of attacks.

Nonhuman Hosts. Some excreted diseases (e.g., shigellosis) are infections exclusively or almost exclusively of man; it is then the control of human excreta that is important in preventing transmission. Many, however, involve other animals either as alternatives to man as host or as hosts of other stages in the life cycle. In the first case, where wild or domestic vertebrate animals act as alternative hosts (such infections are called zoonoses), control of human excreta is not likely to suffice for complete prevention of the infection. In the second case, some excreted helminthic infections have intermediate aquatic hosts. These infections will therefore be controlled if:

(1) excreta are prevented from reaching the intermediate host;

(2) the intermediate hosts are controlled; or

(3) people do not eat the intermediate host uncooked or do not have contact with the water in which the intermediate host lives (depending on its particular life cycle).

Environmental Classification of Excreted Infections

The lists of human pathogens in excreta given in Tables 2-1 and 2-2 are useful only insofar as they show their wide variety and that they are members of one of four groups of organisms: viruses, bacteria, protozoa, and helminths. It is essentially a biological classification. To the sanitation program planner it is interesting, but not very helpful. An environmental classification, which groups excreted pathogens according to common transmission characteristics, is much more helpful in predicting the health impact of sanitation improvements and understanding the health aspects of excreta and sewage treatment and reuse processes. The environmental classification (Table 2-3) developed in volume 3 distinguishes six categories of excreted pathogens, which are described in detail below.

Category I. These are the infections that have a low infective dose (less than one hundred organisms) and are infective immediately on excretion. These infections are spread very easily from person to person wherever personal and domestic hygiene are poor. Therefore, it is likely that changes in excreta disposal technology will have little, if any, effect on the incidence of these infections if they are unaccompanied by sweeping changes in hygiene, which may well require major improvements in water supply and housing, as well as major efforts in health education. The important facet of excreta disposal for the control of these infections is the provision of a hygienic toilet of any kind in or near the home so that people have somewhere to deposit their excreta. What subsequently happens to the excreta (i.e., how it is transported, treated, and reused) is of less importance because most transmission will occur in the home. Although transmission can, and does, occur by complex routes, most transmission is directly person-to-person and therefore the provision of hygienic toilets alone will have a negligible impact. The control measures appropriate to categories I and II, however, merge into each other and really form a continuum (see below). In particular, the parasitic protozoa have some features of each group. The extreme example of a category-I pathogen is the pinworm, Enterobius, whose sticky eggs are laid by emerging females on the anal skin so that autoinfection is by way of scratching fingers without depending much on eggs in the feces. At the other extreme, Giardia has been associated with well-documented waterborne diarrheal outbreaks, and therefore is presumably in part subject to control by excreta management.

Category II. The infections in this category are all bacterial. They have medium or high infective doses ($>10^4$) and therefore are less likely than category-I infections to be transmitted by direct person-to-person contact. They are persistent and can multiply, so that even the small numbers remaining a few weeks after excretion can, if they find a suitable substrate (such as food), multiply to form an infective dose. Person-to-person routes are important but so too are other routes with longer environmental cycles, such as the contamination of water sources or crops with fecal material.

The control measures listed under category I are important, namely, water supply, housing, health education, and the provision of hygienic latrines, but so also are waste treatment and reuse practices. Changes in excreta disposal and treatment practices alone may reduce the incidence of cholera, typhoid, amebiasis, certain shigelloses, and infections due to Balantidium, Hymenolepis, and Yersinia, but are unlikely to be effective against enteroviral infections, salmonelloses (other than typhoid), and infections due to Shigella sonnei, Giardia, Enterobius, and enteropathogenic Escherichia coli, since these latter pathogens are still commonly transmitted within affluent communities in industrialized countries.

Characteristics of Categories I and II

The criteria chosen to separate these categories are infective dose and "length" of the environmental cycle since the aim is to predict the efficacy of sanitation improvements as a control measure. The reason they do not form distinct groups is the variable persistence of the pathogens involved. The extreme type-I pathogen, which has a low infective dose and is environmentally fragile, will clearly tend to be spread in an intrafamilial or other close pattern and depend for its control more on personal hygiene than on sanitation. A low infective dose in an environmentally persistent organism, however, will lead to an infection very difficult to control either by sanitation or by personal and domestic hygiene. Many viruses fall into this category and pose major problems of control so that induced resistence by immunization may be the best approach, as discussed above for poliomyelitis. In category II the role of sanitation improvements is to reduce the efficacy of the longer cycles (this would have less overall benefit in the case of category-I pathogens, where these longer cycles are of little significance).

Category III. This category contains the soil-transmitted helminths. They are both latent and persistent. Their transmission has little or nothing to do with personal hygiene, since the helminth eggs are not immediately infective to man. Domestic hygiene is relevant only insofar as food preparation must be adequate to destroy any infective stages present on food, and latrines must be maintained in a tolerable state so that eggs do not remain on the surroundings for the days or weeks of their latent period. If ova are not deposited on soil or other suitable development sites, transmission will not occur. Therefore, any kind of latrine that contains or removes excreta and does not permit the contamination of the floor, yard, or fields will limit transmission. Because persistence is so long, it is not sufficient to stop fresh feces from reaching the yard or fields. Any fecal product that has not been adequately treated must not reach the soil. Therefore, in societies that reuse their excreta on the land, effective treatment (e.g., storage of excreta for at least a year) is vital prior to reuse.

Category IV. This category contains only the beef and pork tapeworms. Any system that prevents untreated excreta from being eaten by pigs and cattle will control transmission of these infections. Cattle are likely to be infected in fields treated with sewage sludge or effluent. They may also eat feces deposited in cowsheds. Pigs are likely to become infected by eating human feces, which is common in areas where they are employed as scavengers. Therefore the provision of toilets of any kind to which pigs and cattle do not have access and the treatment of all wastes prior to land application are the necessary control methods. It is also necessary to prevent birds, especially gulls, from feeding on trickling filters and sludge drying beds and subsequently depositing tapeworm ova in their droppings on pastures. Personal and domestic cleanliness are irrelevant, except insofar as the use of toilets is concerned.

Category V. These are the water-based helminths that need one or more aquatic hosts to complete their life cycles. Control is achieved by preventing untreated excreta or sewage from reaching water in which these intermediate hosts live. Thus any land application system or any dry composting system will reduce transmission. There are two complications. First, in all cases except *Schistosoma mansoni* and *S. haematobium*, animals are an important reservoir of infection. Therefore any control measures restricted to human excreta can have only a partial effect. Second, in the case of *S. haematobium* it is the disposal of urine that is of importance and this is far more difficult to control than the disposal of feces. Because multiplication takes place in the intermediate hosts (except in the case of the fish tapeworm, *Diphyllobothrium latum*), one egg can give rise to many infective larvae. A thousandfold multiplication is not uncommon. Therefore effective transmission may be maintained at very low contamination levels and the requirements of adequate excreta disposal, in terms of the percentage of all feces reaching the toilet, are very exacting.

Category VI. This category is reserved for excreted infections that are, or can be, spread by excreta-related insect vectors. The most important and ubiquitous of these vectors are mosquitoes, flies, and cockroaches. Among the mosquitoes there is one cosmopolitan species, *Culex pipiens fatigans*, which preferentially breeds in highly contaminated water and is medically important as a vector of the worms that cause filariasis. The other two groups, flies and cockroaches, proliferate where feces are exposed. Both have been shown to carry large numbers and a wide variety of excreted pathogens on their feet and in their intestinal tract, but their importance in actually spreading disease from person to person is in fact controversial, though their nuisance value is great. Flies have also been implicated in the spread of eye infections and infected skin lesions.

The implied control measure is to prevent access of the insects to excreta. This can be achieved by many sanitation improvements of differing sophistication. In general, the simpler the facility, the more care is needed to maintain it insect-free.

Health Benefits of Sanitation Improvements

The theoretical potential for control of excreted infections by sanitation improvements alone and by personal hygiene improvements alone is as follows:

Category	Sanitation alone	Personal hygiene alone
I	Negligible	Great
II	Slight to moderate	Moderate
III	Great	Negligible
IV	Great	Negligible
V	Moderate	Negligible
VI	Slight to moderate	Negligible

Note: See table 2-3 for additional control measures for categories I through VI.

The outstanding difference is between categories I and II together, which depend so strongly on personal and domestic hygiene, and the other categories, which do not. Category-I and -II infections are thus much more likely to be controlled if water availability is improved concurrently with sanitation and if an effective and sustained program of hygiene education is organized. If improvements are made only in the water supply, there will be some reduction in the incidence of category-I and -II infections, but the full health benefits of the water supply improvements will not be realized until excreta disposal improvements are made as well.

If one considers the changes necessary to control category-III and -IV infections, they are relatively straightforward: the provision of toilets that people of all ages will use and keep clean and the effective treatment of excreta and sewage prior to discharge or reuse. The reason why the literature on the impact of latrine programs often does not show a marked decrease in the incidence of category-III through -VI infections is because, although latrines were built, they were typically not kept clean and often not used at all by children or by adults when working in the fields.

Sanitation improvements are thus necessary but in themselves are not sufficient for the control of excreted infections. Without them, excreted infections can never be controlled. But other complementary inputs, such as improved water supplies and sustained hygiene education programs, are essential for success. In some cases, the provision of sanitation improvements and these complementary inputs for the urban and rural poor may necessitate major social and economic changes.

Children

Many of the excreted infections have a very markedly nonuniform distribution of prevalence among different age groups. While all of them are found among people of all ages, many are concentrated in particular age groups. Many are primarily infections of childhood, or they afflict children as well as adults; relatively few are restricted to adults only. This has the greatest relevance for disease control through sanitation improvements, especially in areas where infant and child mortality is high.

In all societies children below the age of about 3 will defecate whenever and wherever they feel the need. A proportion of these under-3-year-olds will be excreting substantial quantities of pathogens. In some societies the stools of these children are regarded as relatively inoffensive and they are allowed to defecate anywhere in or near the house. In this case it is highly likely that these stools will play a significant role in transmitting infection to other children and adults. For example, habits of children that determine the degree of soil pollution in the yard and around the house will largely determine the prevalence and intensity of ascariasis in the household. In contrast, in other societies strenuous efforts are made to control and manage the stools of young children, either by making them wear nappies (diapers) or by cleaning up their stools whenever they are observed. Either of these reactions will have an important controlling influence on the intrafamilial transmission of excreted pathogens.

Between these two extremes there is a whole range of intermediate behavioral patterns with regard to the reaction of adults to the stools of young children. In most poor communities the picture is closer to the first example than to the second. It is important that government and other concerned agencies respond to this situation through health education of parents to encourage a belief that the stools of young children are dangerous and require hygienic disposal. Although the problem is primarily connected with parental attitudes and behavior, the provision of some form of toilet for the disposal of children's stools and, maybe more importantly, a convenient water supply, will greatly assist child hygiene.

Children over 3 years old are capable of using a toilet if one of suitable design is available. Children in the age range 3 to 12 frequently do not use toilets, even where they are available, because:

(1) they find it inconvenient and are not encouraged to use them by adults;

(2) they are afraid of falling down the hole or of being attacked by domestic animals or rodents that may live next to the latrine;

(3) they cannot, because the toilet is physically too big for them; or

(4) they are prevented from doing so by adults who do not want children "messing up their nice clean toilet."

As with the very young children, it is of vital importance that the stools of these children are hygienically disposed of because some of them will be rich in pathogens. The solution lies in a combination of the provision of a toilet that children are happy to use and hygiene education for the parents so that they compel their children to do so.

Groundwater Pollution from On-site Excreta Disposal

On-site disposal of human waste presents a potential hazard of groundwater contamination and, thus, disease transmission from the disposal site through groundwater to users of wellwater. Contaminants are pathogens (bacteria, viruses, helminths, protozoa) and inorganics (principally nitrates and chlorides).

The severity of contamination and the distance pollutants travel depends on factors such as soil type and porosity, distance to and type of underlying rock, groundwater level and hydraulics, composition of waste (presence and characteristics of contaminants), natural contaminant removal processes (filtration, dispersion, sorption), distance to surface water, and the like. The impact on people depends on the type of water service (individual shallow or deep wells, piped systems and their water sources), climate, and so forth.

Clearly, the most serious problem exists where a latrine penetrates the groundwater that provides drinking water through shallow wells located nearby. In such a situation, vault latrines should be used or the water piped to standpipes from a protected well. The most favorable situation exists where the water supply is already a piped system, latrines do not reach groundwater, and soil porosity is low.

It is not possible to establish detailed, universally valid guidelines for horizontal and vertical separation of latrines, drainfields, and wells. Much further work is required to determine the travel distance and survival of pathogens entering the soil through latrines. It is clear, however, that the greater the groundwater abstraction, the more porous or fissured the soil, the greater the distance should be between a latrine and a well. It is generally accepted practice to keep a minimum distance of 10 meters between latrine and well and increase the distance up to 30 meters in gravel and sand. Where wells are equipped with mechanical pumps and supply a large number of people, a groundwater study should investigate and subsequently monitor both water quantity and quality. Such studies, and necessary corrective measures, are beyond the topic of this manual. Qualified professionals should be consulted.

The inorganic pollutant of concern is nitrate, which occurs in groundwater as a result of natural and man-made pollution. Nitrates do not appear to affect adults even at levels far higher than those specified in the World Health Organization (WHO) drinking water standards. On the other hand, bottle-fed infants contract methemoglobinemia at nitrate levels considerably below the WHO standard. As a consequence, it is suggested that where groundwater contains more than 10 milligrams per liter of nitrate nitrogen, the local health officer be consulted to determine the possible impact on infants. Where infants are bottle-fed, acidified milkpowder or other nutritional changes are available to cure or prevent methemoglobinemia. Reportedly, mothers' milk and even cows' milk cannot cause the illness.

CHAPTER 3

COMMUNITY PARTICIPATION

This chapter [1] is concerned with the individual household and community aspects of sanitation program planning. Failure to involve the community that is intended to benefit will almost certainly result in failure of the project. For example, government efforts, extending from 1930 to 1944 and repeated in 1958 and 1974, that tried to impose latrines on a Central American village had by 1977 a success rate of only 11 percent. In contrast, two villages in the same country responded to their own leaders with such enthusiasm that 65 and 85 percent of the villagers now use self-built latrines. At the other end of the scale, both an East Asian and a West African city spent considerable sums to construct sewers that are largely unused because the intended beneficiaries have chosen not to connect to them.

While it is true that possibilities and approaches for community participation are different for villages and cities, personal contacts and dialogue are important in both. The long-range objective of community participation in sanitation program planning is to ensure that the technology selected matches the preferences and resource constraints of the beneficiaries. The technology must satisfy householders' needs at a cost they are willing to pay.

Community participation alone is not sufficient for the successful design and implementation of a sanitation program. Institutional support by government--national, state, and local--is needed to supply technical expertise and support services not available in the community.

A discussion of institutional and organizational managements needed to support the community participation is beyond the scope of this manual. Those interested will find the details in a companion volume. [2]

Characteristics of Community Participation

Community participation should ordinarily include six phases. The first three should be undertaken at the very beginning of project development (they are part of step 1 in Figure 1-1), the fourth toward the end of the selection phase (step 6 of Figure 1-1) and the final two depend upon technical requirements and opportunity patterns. In the first phase unstructured interviews are conducted with a few local leaders (such as political officials, religious leaders, and school teachers) and a small number of households. The purpose of these preliminary interviews is to identify user attitudes and other factors that are likely to determine the engineering design and acceptance criteria listed below. In this phase it is essential to determine what kind of description or model of a technology is needed for the householders to

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[1] Much of this chapter is taken from volume 1 of this report series.

[2] See volume 1.

understand it. A socially acceptable glossary of defecation terms also must be prepared so that local sensitivities and taboos may be protected, and local communication channels and boundaries should be defined. In the second phase a community questionnaire is designed and tested.

The types of information that this questionnaire should elicit include:

(1) the desire of the community for sanitation and water supply improvements, and then as expressed in terms of willingness to contribute to the costs through cash contributions and/or labor and materials;

(2) preference for private or communal facilities (e.g., do the latter represent opportunities for socializing or do they lead to crowding and quarreling?);

(3) health, sickness, and nuisance as they are perceived to be affected by water supply and sanitation practices;

(4) attitudes toward convenience as measured by latrine or standpipe location, abundance or capacity of water supply systems, and reliability of service;

(5) water quality preferences in terms of color, taste, odor, temperature, etc.;

(6) aesthetic features of sanitation alternatives such as superstructure color and materials or squatting plate design;

(7) attitudes towards visibility, means of removal, and so forth, of stabilized wastes, and towards conservation, reuse or reclamation (biogas, fertilizer, aquaculture, stock and garden watering, and the like) of wastes;

(8) importance attached to local autonomy that might be lost if a higher authority were to assume part or all of the responsibility for funding, fee collection, construction, operation, and maintenance of the improved facilities;

(9) community or peer pressure for joining and supporting "unity and progress" groups and the like; and

(10) confidence in local or visiting political and technical authorities.

Other factors about which information is essential for design or implementation include land tenure and the customary manner in which local committees are formed.

In the third phase, structured interviews are conducted using the questionnaire developed (and modified if necessary) in the second phase. At least thirty households should be interviewed, and care must be taken to ensure that they are representative of the social and income groups of the community; usually, information gained in the unstructured, preliminary interviews can be used to select representative households.

Interviews should include the women since they are both knowledgeable about water use and responsible for training children in personal hygiene and sanitation. It should always be remembered by the interviewer that the most reliable comprehensive answers to questions on sanitation will come from those who are most concerned about sanitation.

After the formal interviews, the responses should be evaluated by the program behavioral scientist. This information is then used by the engineer and economist to develop a list of socially acceptable, technically feasible, least-cost alternatives.

In the fourth phase, a meeting should be held between the program behavioral scientist and the community or its representatives at which the former presents the alternative technologies and their costs. At a follow-up meeting conducted at an early date, a technology option or options should be selected. If necessary, limited demonstration projects may be built and operated.

If a significant proportion of the community population (say, 50 percent) is not interested in cooperating in a sanitation project by the end of the community participation and assessment program, it will ordinarily be better to shift the project and resources to another community. Two additional warnings are in order: important differences between community preference and design or service level, whether higher or lower, are seldom resolved by more education or information. Second, schemes that depend on wealthier individuals involuntarily supporting sanitation services for others ordinarily do not work. For example, wealthy homeowners are not likely to abandon operating septic tanks and pay high sewer connection charges so that poor neighborhoods can be served by the same sewer system.

The fifth phase occurs either in parallel with the technology selection or as a result of it. The community will have to organize the implementation and subsequent operation and maintenance of the facilities to be constructed. If there is a formal organizational structure in the community, it may be used to organize project implementation and operation. If no structure exists, special arrangements will have to be made for the project.

Construction work should be performed with the assistance of the technician of the technical support agency, but under local leadership if possible. It is important that the community ensures that some of its members are trained by the technician during this process.

Some of the aspects involved in a successful construction program are the site selection for communal and private facilities; the purchase of materials not available in the community; the distribution of materials needed to construct individual facilities; prompt delivery by the community of materials provided in lieu of cash contributions; organizing work parties and keeping records of time, cash, or materials provided by community members; supplying technical assistance for the construction and initial operation of the facilities; and external input from the technical support agency.

Phase six is the operation and maintenance of the facilities. In the case of communal systems this involves regular operation, maintenance, occasional repairs, and the collection of funds to pay for recurrent expenses. In addition, performance should be monitored by the technical agency, in collaboration with the community, and information disseminated to other communities so that lessons learned from the success or failure in one can be used in the design and implementation of programs in others. Regular visits should be made at short intervals in the beginning and at least once a month once the community has become familiar with the tasks of operating the facilities. Provisions also should be made for rapid contact in cases of emergency (failure of equipment, suspected water contamination, and the like).

Institution-Community Linkage

Many of the community participation aspects of sanitation program development depend upon and influence institutional structures. Although it has been assumed that the necessary institutional support exists, it may be useful to conclude this chapter with a simplified description of the institutional steps required to facilitate and support community involvement, which are as follows:

1. Establish a support unit for water supply and sanitation in existing regional agencies or form an independent support unit. The staff will represent a mix of disciplines and will probably include engineers, hydrogeologists, a behavioral scientist, an economist, accountants, plumbers, mechanics, electricians, well drillers, purchasing agents, and health educators.

2. Establish design and operating standards and village selection/priority criteria, conduct specialized tasks such as hydrogeological surveys, management training/operating assistance, and the like.

3. Train community workers in low-cost water supply and sanitation technology and hygiene promotion and community organization.

4. Train community workers in health care and nutrition.

5. Canvass and organize selected communities. Plan, design, and implement prototype projects to complete the training of community workers.

6. Assign community workers in teams to designated areas to canvass and organize communities.

7. Assist communities in constructing facilities.

8. Maintain a limited number of community workers as roving operation and maintenance advisers and monitors for completed projects. Assign all other community workers to new areas where successful projects can be replicated.

9. Provide technical assistance through support unit. Maintain a stock of spare parts administered by the support unit.

10. Monitor the operation and quality of service, disseminate information, and provide continuous training programs for community workers and local staff.

In summary, the degree of community participation and its willingness to pay for improved service levels by contributions of money, labor, or materials depends fundamentally upon household income levels and perceived needs. Whether a feasibility study results in a project that properly meets the needs of the community depends upon the accuracy, completeness, and timeliness of information exchanged between the residents and those who are conducting the feasibility study. The analysis of social factors and conduct of the interviews should be the responsibility of people accepted by the community; they are too important to be entrusted to strangers.

CHAPTER 4

ECONOMIC ANALYSIS OF SANITATION TECHNOLOGIES

Once the technologies that are technically infeasible for the site being considered have been eliminated by the project engineer, it is necessary to rank the remaining technically feasible technologies by some meaningful scale in order that the most appropriate one may be selected.1/ Implicit in this is the need for a common basis for the objective comparison of the remaining technologies that reflects both the positive and negative consequences of adopting each of them.

Ideally a cost-benefit analysis should be used to rank alternatives. Unfortunately, as is true of many public services, it is impossible to quantify most of the benefits (such as those of improved health and user convenience) of a sanitation system. In general, there is no completely satisfactory way to get around this difficulty. Only in the case of mutually exclusive alternatives with identical benefits can one safely select the one with the least cost. Where there are differences in the levels of service provided by the various alternatives, the least-cost choice will not necessarily be the one that is economically optimal. For this reason a least-cost comparison will not normally provide sufficient information to select the most appropriate sanitation technology. Nonetheless, if properly applied, it will provide a reasonably objective basis for comparison that reflects the cost trade-offs corresponding to different levels of service. Once comparable cost data have been developed, the users or their community representatives can make their own determination of how much they are willing to pay to obtain various standards of service.

Economic Costing

The basic purpose behind the economic costing of sanitation technologies (or the economic costing of any other development activity) is to give policymakers a basis for their decisions by providing a price tag for a given level of service that represents the opportunity cost to the national economy of producing that service. Three principles must be followed in preparing estimates:

(1) all relevant costs must be included;

(2) each cost must be properly evaluated; and

(3) the assumptions used for costing different technologies must be mutually consistent.

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1. Much of this chapter is taken from volume I of this report series.

The first principle of economic costing is that all costs to the economy, regardless of who incurs them, should be included. In comparing the costs of different sanitation technologies, too often only those costs met by the administrative (usually municipal or state) authority are considered in the cost comparison. The costs borne by the household or of complementary services (e.g., water for flushing) are often ignored. In analyzing the financial implication to the authority of alternative technologies such a comparison would be appropriate. For an economic comparison, however (i.e., for the determination of the least-cost technology with respect to the national economy), it is necessary to include all costs attributable to a given alternative irrespective of whether they are borne by the household, the administrative authority, the national government, or whomever. On the other hand, some financial costs should be excluded from the economic comparison. Examples of costs that should be ignored are subsidies and taxes since these represent a transfer of money within the economy rather than a cost to it.

The determination of which costs to include should rest on a comparison of the situation over time both with and without the project. This is not the same as a simple "before and after" comparison. Rather than using the status quo as the "without" scenario, it is essential to estimate how the current situation would improve or deteriorate over the project period if the project were not to be undertaken.

Once the relevant costs have been identified, the second principle of economic costing concerns the prices that should be used to value these costs. Since the objective of economic costing is to develop figures that reflect the cost to the national economy of producing a good or service, the economist is concerned that unit prices represent the actual resource endowment of the country.

Because governments often have sociopolitical goals that may be only indirectly related to economic objectives, some market prices may bear little relation to real economic costs. For this reason it is necessary to adjust market prices in the economic costing exercise so that they represent more accurately "real" unit costs (in the sense of reflecting their impact on the national economy), instead of using actual market prices, which may be fixed for sociopolitical reasons. This adjustment of market prices to reflect opportunity costs is sometimes known as "shadow pricing."

The calculation of these shadow rates, or conversion factors, is a difficult task that requires intimate knowledge of a country's economy. It is rarely (if ever) worthwhile for an economist or engineer involved with sanitation program planning to take the time to collect data and calculate conversion factors directly. Rather, he or she should check with the ministry of planning or economic affairs to see if the figures have already been determined.

In the economic costing of sanitation technologies there are four shadow rates that normally need to be incorporated into the analysis. These are:

(1) the unskilled labor wage shadow factor;

(2) the foreign exchange shadow factor;

(3) the opportunity cost of capital; and

(4) the shadow price of water, land, and other direct inputs.

These are briefly discussed in turn.

Unskilled labor. Many governments enact minimum wage legislation. The normal effect of this is that unskilled labor is economically overvalued; that is, the financial reward (pay) of an unskilled laborer is higher than that he would receive in the absence of minimum wage legislation. On the one hand, if a country has a very large pool of unemployed laborers, the unskilled labor wage shadow factor would be close to zero because there is almost no cost to the national economy that results from employment of such people, since they would otherwise be unemployed and so be producing nothing. On the other hand, if a country has few unemployed unskilled workers, then the shadow factor would be 1, as this situation is an indication that the market wage fairly reflects economic value. Generally the shadow factor for unskilled labor in developing countries is in the range of 0.5 to 1.0.

Foreign exchange. Many governments do not permit free movement of the exchange rate of foreign currency for their national currency in the international money markets. Instead, they fix its value, often in terms of the currency of a major trading partner such as the United States or Japan. Sometimes this results in the currency being overvalued; imports thus cost fewer units of the national currency than they would if the government allowed the currency to trade freely on the international market, and exports are overpriced in terms of their foreign currency value. The foreign exchange shadow factor is the ratio of the shadow exchange rate (what the currency would be worth in a freely trading international market) to the official exchange rate fixed by the government; expressed in this way the shadow factor is thus greater than 1 whenever the local currency is overvalued or import restrictions are high.

Opportunity cost of capital. This is defined as the marginal productivity of additional investment in its best alternative use. It can also be thought of as the price (or yield) of capital. In many developing countries, however, capital is a scarce commodity and therefore has a high opportunity cost. A government might decide for sociopolitical reasons to make available loans to householders at a low rate of interest to enable them to build, say, ventilated improved pit (VIP) latrines. The economic cost of this decision is the yield that the government would have received had it invested its capital in the best alternative way. The opportunity cost of capital is thus expressed as a percentage; in developing countries it usually ranges from 8 percent to 15 percent.

Water, land, and other direct inputs. The prices of some inputs of sanitation systems are controlled by governments or incorporate government subsidies. For example, land for the construction of waste stabilization ponds may be owned by the government because it is near a public airport. The government may decide to transfer it to the sewerage authority for no financial cost. Its economic cost, however, should be calculated as what it would have been worth had it been sold on the market to a farmer or industry that wished to locate there.

Other prices that may need adjustment to reflect real resource costs are those of publicly produced outputs such as water and power. It is usually not possible to estimate directly what a free market price would be for these items because the government normally has a monopoly in their production. Nevertheless, the shadow price of water or power can be approximated by calculating its average incremental production cost. A good method for doing this is described below and shown in the appendix to this chapter.

For most developing countries, where labor is abundant but capital and foreign exchange are scarce, the effect of shadow pricing is to decrease the cost of unskilled labor and to increase the cost of both capital and imported goods. As shadow pricing removes distortions due to political decisions (e.g., minimum wage legislation, overvaluation of local currencies, and the provision of development capital at low rates of interest), it is extremely valuable in the identification of the most appropriate sanitation technology given the actual resources of the country. An example of the use of shadow pricing is given in the appendix to this chapter.

In addition to these adjustments for shadow prices, economic costs differ from financial costs in that they are based on incremental future investments rather than average historical investments. This principle rests on the idea that costs already incurred ("sunk" costs) should be disregarded in making decisions about future investments. Thus, in analyzing the real resource cost of a given technology, it is necessary to value the components of that technology at their replacement costs rather than at their actual historical prices. In the case of sanitation systems this is particularly important in the costing of water. Because cities develop their least expensive sources of water first, it generally becomes more and more costly (even excluding the effect of inflation) to produce and deliver an additional liter of water as the city's demand grows. By using the average cost of producing today's water, one is often seriously underestimating the cost of obtaining additional water in the future. The decision to install a conventional sewerage system with high-volume cistern-flush toilets will increase domestic water consumption by around 50 to 70 percent. Thus, in calculating the costs of such an alternative, it is extremely important to value properly the cost of the additional water that will be required. The economic cost of this additional water is its average incremental production cost; it is not the cost charged to the consumers or its current average production cost.

It is often difficult to calculate comparable costs when considering low-cost sanitation as an alternative to sewerage. In the former case, the facility is fully used almost immediately by its "design population." In the latter, many of the components exhibit economies of scale and are therefore sized to meet a design flow that usually does not arise for many years. With such a facility all the investment costs are incurred at the beginning of its lifetime while the benefits (services) are realized gradually over time. Just as costs incurred in the future have a lower present value than those incurred today, benefits received in the future are less valuable than those received immediately. In the derivation of per household costs this means that serving a person 5 years hence is not worth as much as serving the same person now. To divide the cost of a sewerage system by its design population would greatly understate its real per household cost when compared with that of a system that is fully utilized upon completion.

One of the best methods to overcome this problem of the differing capacity utilization rates of different systems is the average incremental cost (AIC) approach. The per capita (or household) AIC of a sewerage system is calculated by dividing the sum of the present value of construction costs and incremental operating and maintenance costs by the sum of the present value of incremental persons (or households) served; the appropriate equation is:

$$AIC_t = \frac{\sum_{t=1}^{t=T} (C_t + O_t)/(1 + r)^{t-1}}{\sum_{t=1}^{t=T} N_t/(1 + r)^{t-1}}$$

where t = time in years;

T = design lifetime in years (measured from start of project at $t = 0$);

C_t = construction costs incurred in year t;

O_t = incremental (from year $t = 0$) operation and maintenance costs incurred in year t;

N_t = additional people or households (from year $t = 0$) served in year t;

r = opportunity cost of capital in percent times 10^{-2}.

It is essential that all costs used in the equation have been appropriately shadow priced. Note that, for a system that is fully utilized upon construction, the equation reduces to merely the sum of the annuitized capital costs and annual operating and maintenance costs divided by the design population.

In practice it is often easier to calculate the AIC of a sewerage system on a volumetric, rather than a per capita, basis. The AIC per cubic meter of sewage is calculated from year-by-year projections of the total wastewater flow. The resulting volumetric costs can then be transformed into per capita (and per household) costs using the per capita wastewater flow. An example is given in the appendix to this chapter.

An additional problem in deriving comparable costs for different sanitation technologies is the differing abilities of the technologies to handle sullage. Thus if sewerage (including sullage collection) is one alternative, the cost of sullage disposal in, for example, road drains should be included in the cost of other sanitation alternatives unless the road drains would be built anyway for flood control, in which case it is necessary only to include the additional costs incurred as mentioned above. The guiding principle, again, is to compare the conditions with and without the project.

In general the data necessary for the calculation of comparable economic costs can be collected fairly early in the design process, after preliminary designs have been prepared. This has the advantage of providing an early warning if, as is frequently the case, most of the alternative designs are too costly relative to the resources likely to be available. It thus saves the trouble of preparing final designs for those technologies that are outside the bounds of affordability. Therefore economic costing should be seen as an early screening of the various sanitation technologies that have passed the basic technical and social feasibility tests.

Financial Costs

The purpose of deriving economic costs is to make a meaningful least-cost comparison among alternatives. Such a comparison is extremely useful to the planner and policymaker. The consumer, however, is much more interested in financial costs, i.e., what he will be asked to pay for the system and how the payment will be spread over time. The difficulty in developing financial costs is that they are entirely dependent upon policy variables that can range widely. Whereas economic costs are based on the physical conditions of the community (e.g., its abundance or scarcity of labor, water, and so forth) and therefore are quite objective, financial costs are entirely subject to interest rate policy, loan maturities, central government subsidies, and the like. For example, the financial cost of a sanitation system for a community can be zero if the central government has a policy of paying for them out of the general tax fund. Thus financial costs cannot be used to make judgments about least-cost alternatives.

To promote the economically efficient allocation of resources, of course, financial costs should reflect economic costs as closely as possible, given the government's equity goals and the degree of distortion in other prices in the economy. In deriving financial costs in any particular case, it is necessary to talk with central and local government officials to determine their financial policies and noneconomic objectives. If the government places a high priority on satisfying the basic needs of all of its citizens, then it may be willing to subsidize part or all of the construction cost of a simple sanitation system. The general policy of international lending agencies such as the World Bank is that, if the cost of the minimal sanitation facility necessary to provide adequate health is more than a small part of the household income (say, 5-10 percent), then the central or local government should attempt to subsidize its construction to make it affordable. Any operation or maintenance costs should be borne by the beneficiary. If, however, some consumers wish to have better or more convenient facilities, they should pay the additional cost themselves. Since the majority of the poorest people in most countries live in rural areas, it is usually not appropriate to subsidize urban services from central tax revenues.

In general it is necessary to calculate several sets of financial costs based on different assumptions about municipal or central government subsidies. The first set, which is hereafter called the base financial cost, is that which assumes no financial subsidy. For an on-site system with a very short construction period and little requirement for municipal maintenance, the engineer's estimate of construction costs (in market prices) is simply annuitized over the life of the facility at the prevailing (market) interest rate. If self-help labor can be used for part of the construction, then the cost of hiring that labor should be subtracted from the total before annuitizing. To this annual capital cost must be added any operating and maintenance costs that will be required. Then this total base financial cost can be compared with household incomes to check affordability. If the technology is deemed affordable by the target population, then the only financial arrangements that will be required at the outset are those necessary to aid consumers in securing loans from commercial and public banks. If the technology's base financial cost is not affordable by the households to be served, and if lower-cost solutions are infeasible or unacceptable, then various options involving increased self-help input, deferred or low-interest loans, partial construction grants, and the like should be used to compute alternative sets of financial costs. Before any of these are offered to the consumer, however, it is obviously necessary to obtain local and/or central government funding to cover the financing gap.

The development of financial costs is more difficult for technologies with off-site investments and the accompanying need for centralized management and operation. There is a large body of literature on accounting systems for public utility enterprises, and the subject cannot be fairly summarized in this brief chapter.

Cost of Community Support Activities

The construction cost figures used for both the economic and financial analyses do not include the cost of community organization, hygiene education and technical assistance, and government administrative support not directly related to the construction of the facilities that are normally provided to complement a water supply or sanitation program. Unless otherwise noted, it is assumed that assistance provided by government for health education and technical assistance is paid for from regular budgetary resources. Where additional assistance is required, the cost should be estimated and specific funding arrangements made. Assistance needs vary too widely from community to community to permit the estimation of a useful average per capita cost figure.

APPENDIX

EXAMPLES OF ECONOMIC COSTING

1. Economic costing of a ventilated improved pit (VIP) latrine.

(a) Assume that all materials, except the vent-pipe, cement, and reinforcing steel (for the concrete squatting plate), are manufactured locally. Let the costs (in units of national currency, unc) be:

Local materials	100 unc;
Imported materials	60 unc.

(b) Assume that skilled labor is used in building the squatting plate and superstructure and for general supervision, and that unskilled labor is used to excavate the pit, to mix the concrete, and generally to assist the skilled labor. Let the costs be:

Skilled labor	30 unc;
Unskilled labor	70 unc.

(c) Assume that the household can be expected to spend 10 unc per year on minor repairs and cleaning materials, and that the repairs are done by the householder and the cleaning material is manufactured locally.

(d) Assume the following:

Unskilled labor shadow factor	0.7;
Foreign exchange shadow factor	1.3;
Opportunity cost of capital	12 percent;
Official rate of exchange	1 US$ = 2.80 unc;
Household size	6 persons.

(e) Assume that the pit latrine is designed to last 10 years and that no items can be reused at the end of that period.

The calculated costs are presented in Table 4-1. The following points should be noted:

(1) The annuity or capital recovery factor (CRF) can most easily be obtained from a book of financial or compound interest tables or by using a financial calculator. It can also be calculated, however, from the equation:

$$CRF = \frac{r\ (1 + r)^N}{(1 + r)^N - 1};$$

where r = opportunity cost of capital, percent x 10^{-2} and

N = design lifetime, years.

Here r = 12 percent and N = 10 years, so that the CRF is 0.177.

(2) The annuitized annual cost (in unc) of each capital item is obtained by multiplying its cost (in unc) by the CRF and by the appropriate shadow factor, if any.

(3) The annual cost in U.S. dollars is calculated by converting the shadowed local cost at the official rate of exchange.

Table 4-1: Annual Economic Costs of a Ventilated Improved Pit (VIP) Latrine

Item	Total cost (unc)	Life (years)	Shadow factor	Adjusted annual cost (unc)	Adjusted annual cost (US$)
Materials					
Local	100	10	None	17.7	6.3
Imported	60	10	1.3	13.8	4.9
Labor					
Skilled	30	10	None	5.3	1.9
Unskilled	70	10	0.7	8.7	3.1
Maintenance	10	1	None	10.0	3.6
Total					
Per household				55.5	19.8
Per capita				9.3	3.3

2. Economic costing of a conventional sewerage scheme.

Sewerage costs are divided into three groups: household costs, collection costs, and treatment costs.

Household costs

These include all the toilet and plumbing fixtures, the connection to the street sewer, and the superstructure (in the case of a toilet located inside the house, this may be calculated as the toilet floor area times the construction cost per square meter--excluding from the latter the toilet and plumbing fixtures, to avoid including these twice). All these costs must be shadow priced and it is thus necessary to determine separately the costs of unskilled labor and imported items. These capital costs are then converted to annual costs by multiplying by the appropriate CRF as described in the previous example.

Annual operation and maintenance costs are then calculated, using the AIC of water for the unit cost of the flushing water necessary.

Collection and treatment costs

These include all material and installation (labor) costs for the sewer network and its appurtenances, such as manholes and pumping stations, and for the treatment works, including land costs. Capital costs for collection and treatment should be calculated separately since they may be incurred at different times during the construction period and may also have different design lifetimes.

Example

Household costs are excluded from the example since they are calculated in the same way as those of the pit latrine. It is important to note here only that the design lifetime of the household components is not likely to be the same as those of the collection system and treatment works.

Assume that the collection network and treatment works are constructed over a 5-year period. Assume further that the shadowed costs are as follows and incurred in the year(s) stated:

Collection costs

(a) All sewers, force mains, manholes: 4,000,000 unc; evenly over the 5 years.

(b) Pumping stations (including mechanical and electrical installation): 400,000 unc; in fifth year.

(c) Engineering design: 200,000 unc; evenly over first and second years.

(d) Operation and maintenance: 150,000 unc per year when system is fully utilized.

Treatment costs

(a) Land: 2,000 unc; in first year.

(b) Fencing: 10,000 unc; in third year.

(c) Engineering design: 15,000 unc; in third year.

(d) Treatment works: 900,000 unc; evenly over last 3 years.

(e) Operation and maintenance: 100,000 unc per year at full capacity.

Assume also that: the design population is 250,000; the wastewater flow is 200 liters per capita daily; 50 percent of the design population is served upon completion of construction, increasing linearly to full utilization by the beginning of the eleventh year from completion; the design lifetime of both the collection system and treatment works is 40 years (measured from completion); and the opportunity cost of capital is 12 percent. Note that the costs given above are assumed to have been shadow priced already for unskilled labor and foreign exchange components. Operation and maintenance costs are assumed to vary with the population served, being 50 percent of the figure given above upon completion, increasing to 100 percent by the beginning of the eleventh year from completion.

The costing procedure is as follows:

(1) Construct a table, similar to Table 4-2, in which all the costs incurred and the total volume (in cubic meters) of wastewater generated in each year are entered under the various headings as shown. The effect of inflation should be ignored in this calculation so that all costs are in constant prices.

(2) As shown in Table 4-3, convert these costs and volumes to their present values by using a set of financial tables, a financial calculator, or the equation:

$$PV = C_t \;/\; (1 + r)^{t-1};$$

where PV = the present value of C_t;

C_t = cost incurred (or total wastewater volume produced) in year t; and

r = opportunity cost of capital.

Table 4-2. Actual Costs (in unc) and Wastewater Flows (constant base year prices)

	Collection		Treatment		
Year	Capital	Operation & maintenance	Capital	Operation & maintenance	Wastewater flow (thousands of cubic meters)
1	900,000	0	2,000	0	0
2	900,000	0	0	0	0
3	800,000	0	325,000	0	0
4	800,000	0	300,000	0	0
5	1,200,000	0	300,000	0	0
6	0	75,000	0	50,000	9,125
7	0	82,000	0	55,000	10,038
8	0	90,000	0	60,000	10,950
9	0	97,500	0	65,000	11,863
10	0	105,000	0	70,000	12,775
11	0	112,500	0	75,000	13,688
12	0	120,000	0	80,000	14,600
13	0	127,000	0	85,000	15,513
14	0	135,000	0	90,000	16,425
15	0	142,500	0	95,000	17,338
16	0	150,000	0	100,000	18,250
17	0	150,000	0	100,000	18,250
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
44	0	150,000	0	100,000	18,250
45	0	150,000	0	100,000	18,250

Table 4-3. Present Values of Costs (in unc) and Wastewater Flows (constant base year prices)

	Collection		Treatment		
Year	Capital	Operation & maintenance	Capital	Operation & maintenance	Wastewater flow (thousands of cubic meters)
1	900,000	0	2,000	0	0
2	803,571	0	0	0	0
3	637,755	0	259,088	0	0
4	569,424	0	213,534	0	0
5	762,621	0	190,655	0	0
6	0	42,557	0	28,371	5,177
7	0	41,543	0	27,864	5,085
8	0	40,711	0	27,140	4,953
9	0	39,378	0	26,252	4,791
10	0	37,864	0	25,242	4,606
11	0	36,221	0	24,147	4,407
12	0	34,497	0	22,998	4,197
13	0	32,597	0	21,817	3,981
14	0	30,938	0	20,625	3,764
15	0	29,158	0	19,438	3,547
16	0	27,404	0	18,269	3,334
17	0	24,468	0	16,312	2,976
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
44	0	1,147	0	764	139
45	0	1,024	0	682	124
Present value of column	3,673,371	612,689	665,277	408,702	74,575

Note: $\text{AIC} = \dfrac{3{,}673{,}371 + 612{,}689 + 665{,}277 + 408{,}702}{74{,}575{,}000} = 0.07 \text{ unc/m}^3$

(3) Calculate the AIC of the collection and treatment components by adding together the sums of the present values of the capital and operation and maintenance costs for both components, and dividing by the sum of the present value of the wastewater volumes as shown in the last line of Table 4-3. This gives the AIC of collection and treatment in unc per cubic meter from which the annual per capita AIC can be calculated, as the per capita wastewater flow is known to be 200 liters per capita daily (73 cubic meters/year). In this example the AIC per cubic meter is 0.072 unc, or 5.2 unc per capita per year. The total AIC of the whole sewerage scheme in unc per capita per year is then obtained by adding in the shadowed annual per capita household capital and operation and maintenance costs. This may be expressed in U.S. dollars by converting at the official exchange rate.

PART TWO

SANITATION PROGRAM

PLANNING

CHAPTER 5

SANITATION TECHNOLOGY COMPARISONS

In chapter 8, on-site technologies requiring no community organization for operation and maintenance are briefly described. Detailed descriptions, design details and drainage for these technologies are found in Volume XI "A Field Manual". Technologies requiring an organization for day-to-day operation and maintenance are described in chapters 9 through 12.

A variety of sanitation technologies exist. The principal ones are shown on Table 5-1, "Descriptive Comparison of Sanitation Systems." Those considered suitable for application in developing countries are described in chapters 8 through 12.

The most common approach to making comparisons of sanitation technologies is to define the comparative criteria and then use some kind of matrix that displays the putative performance of each alternative in relation to the stated criteria in the manner shown in Table 5-1. The comparison is purely descriptive and no overall ranking or conclusions are attempted. Table 5-1 is essentially a guide for nontechnical readers and a convenient summary for professionals. Its most useful function may be to exclude certain technologies in a given situation, rather than to select the best.

More complex approaches to matrix comparisons are possible. For example, each criterion may be weighted numerically and the degree to which each technology satisfies each criterion may be assigned a score on a numerical scale, so that weighted performance figures can be obtained for each technology and the technologies ranked accordingly. However, ranking technologies in this way not only produces a numerical comparison of spurious precision, but also one that may be, to the users at least, irrelevant. Moreover, in any given community there are always basic physical and cultural attributes that, in conjunction with the existing level of water supply service and the community's general socioeconomic status, limit the choice of technologies considerably, irrespective of the overall scores achieved in a numerical matrix comparison of all possible technologies. These factors and their influence on technology choice are discussed below.

Water Supply Service Levels

A convenient supply of water is quickly reflected in the amount used and, hence, in the options available for its disposal. It has been found that neighborhood standpipes ordinarily supply 20 to 25 liters per capita daily; when a yard tap is provided, water use increases to 50 liters per capita daily, and when water is supplied through a tap inside the house, water use becomes 50 to 100 liters per capita daily, which is about the limit for on-site disposal of sullage.

Hand-carried Supplies

Clearly, ventilated improved pit (VIP) latrines, Reed Odorless Earth Closets (ROECs), ventilated improved double-pit (VIDP) latrines, and double-vault composting (DVC) toilets are possible choices since they require no water, except for toilet hygiene. Equally, cistern-flush toilets with either

Table 5–1 Descriptive Comparison of Sanitation Technologies

Sanitation technology	Rural application	Urban application	Construction cost	Operating cost	Ease of construction	Self-help potential	Water requirement	Required soil conditions	Complementary off-site investments[a]	Reuse potential	Health benefits	Institutional requirements
Ventilated improved pit (VIP) latrines and Reed Odorless Earth Closets (ROECs)	Suitable	Suitable in low/medium-density areas	L	L	Very easy except in wet or rocky ground	H	None	Stable permeable soil; groundwater at least 1 meter below surface[b]	None	L	Good	L
Pour-flush (PF) toilets	Suitable	Suitable in low/medium-density areas	L	L	Easy	H	Water near toilet	Stable permeable soil; groundwater at least 1 meter below surface[b]	None	L	Very good	L
Double-vault composting (DVC) toilets	Suitable	Suitable in very low-density areas	M	L	Requires some skilled labor	H	None	None (can be built above ground)	None	H	Good	L
Self-topping aquaprivy	Suitable	Suitable in low/medium-density areas	M	L	Requires some skilled labor	H	Water near toilet	Permeable soil; groundwater at least 1 meter below ground surface[b]	Treatment facilities for sludge	M	Very good	L
Septic tanks	Suitable for rural institutions	Suitable in low/medium-density areas	H	H	Requires some skilled labor	L	Water piped to house and toilet	Permeable soil; groundwater at least 1 meter below ground surface[b]	Off-site treatment facilities for sludge	M	Very good	L
Three stage septic tank	Suitable	Suitable in low/medium density areas	M	L	Requires some skilled labor	H	Water near toilet	Permeable soil; groundwater at least 1 meter below ground surface[2]	Treatment facilities for sludge	M	Very good	L
Vault toilets and cartage	Not suitable	Suitable	M	H	Requires some skilled labor	H (for vault construction)	Water near toilet	None (can be built above ground)	Treatment facilities for night soil	H	Very good	VH
Sewered PF toilets, septic tanks, and aquaprivies	Not suitable	Suitable	H	M	Requires skilled engineer/builder	L	Water piped to house	None	Sewers and treatment facilities	H	Very good	H
Sewerage	Not suitable	Suitable	Very high	M	Requires skilled engineer/builder	L	Water piped to house and toilet	None	Sewers and treatment facilities	H	Very good	H

[a] On-or off-site sullage disposal facilities are required for nonsewered technologies.

[b] If groundwater is less than 1 meter below ground, a plinth can be built.

L, low; M, medium; H, high; VH, very high.

conventional sewerage or septic tanks and soakaways are technically infeasible, as are sewered pour-flush (PF) toilets since insufficient sullage would be generated. The principal problem is whether PF toilets and vault toilets (which also have a PF squatting slab) are feasible or not. Is sufficient PF water likely to be hand carried into the toilet? The inconvenience of carrying PF water to the toilet might be considered by the users to outweigh the advantages PF toilets have over pit latrines, and a VIP latrine might well be preferred at least until the water supply is upgraded when the latrine can also be upgraded to a PF toilet (chapter 7). On the other hand, if the PF or vault toilet is to be located inside the house, social aspirations for an "inside" toilet might outweigh the inconvenience of carrying the PF water.

Yard Taps

PF toilets and vault toilets are now possible choices, but not cistern-flush toilets. If sullage generation exceeds 50 liters per capita daily, sewered PF toilets also become technically feasible. Direct discharge to sewers is not advisable, however, because the small amount of water needed for a PF toilet is rarely sufficient to carry excreta the distance required.

In-house Connections

Cistern-flush toilets with conventional sewerage or septic tanks and soakaways are now technically feasible, and the decision of whether to install them is an economic and financial one.

Soil Conditions

Soil conditions are important for all sanitation technologies except those that can be completely contained above ground level. The principal two technologies that fall into this category are DVC toilets and vault toilets.

Soil stability is important for VIP latrines, ROECs, and PF toilets. In unstable soils pits must be lined, often to their bases. Soil permeability is important for these technologies as well, and also for septic tank soakaway trenches. In impermeable soils these technologies are infeasible.

If the groundwater table is within 1 meter of the ground surface, VIP latrines, ROECs, and PF toilets are of doubtful feasibility. They may be feasible if the soil is sufficiently permeable that the liquid level in the pit is not more than 0.5 meter below ground level, but the pit may be unstable unless supported to its base, and mosquito breeding is likely to be a problem except in PF toilets. The toilet may need to be raised as shown in Figure 8-12. For ROECs and single-pit VIPs, which require large pits, pit excavation and lining are likely to be hazardous and very difficult.

The presence of rock near the ground surface creates difficulties for all technologies affected by soil conditions. It makes conventional sewerage even more expensive and sewered PF systems comparatively more attractive, though still very costly. VIP latrines, ROECs, and PF toilets become considerably more expensive, but the temptation to build pits with an effective life of less than 2 years should be strongly resisted.

Housing Density

In very densely populated urban areas, VIP latrines and ROECs are infeasible, and PF toilets and septic tanks with soakaways are feasible only under favorable circumstances. Conventional sewerage, sewered PF systems, and vault toilets are feasible. If site gradients are steep enough to provide self-cleansing velocities, PF toilets discharging directly to sewers without the wastes first entering a settling tank are also feasible. The choice among these possibilities is decided essentially on economic grounds, although access for service vehicles and sullage disposal facilities is important for vault toilets (and the former also for desludging sewered PF settling tanks).

It is not easy to define at what population density on-site systems such as VIP latrines, ROECs, PF, and DVC toilets become infeasible. The figure is probably most commonly around 250 to 300 persons per hectare, although it depends to some extent on the type of housing; higher densities (up to around 500 to 600 persons per hectare) may often be possible if double-storied buildings are used; PF toilets may be a possibility at even higher densities. The main point is to determine, in any given situation, whether or not there is sufficient space on the plot to provide two alternating pit sites that have a minimum lifetime of 2 years. Two years is the absolute minimum lifetime, as noted above, but the minimum desirable lifetime is 5 years, with 10 years being preferred for VIP latrines and 15 to 20 years for ROECs.

Costs

Clearly all technologies should be least-cost solutions and must be affordable. The decision of which technology to select should be based on economic (rather than financial) costs since the former represent the real resource cost to the national economy. The technology with the lowest economic cost is generally the one that should be selected. If the users are willing to pay the full economic cost of a more expensive technology (so that there is no need for subsidy), they should be free to select that technology. An example of total annual economic (shadowed) costs per household of the different technologies may be obtained from Table 5-2, which summarizes costs collected in 1977-78 by the World Bank.

The costs perceived by the municipality (or other implementing agency) and by the users are the financial costs that they will have to incur. Municipalities may be sophisticated enough to consider financial "life cycle" costs (in effect the present value of the costs to be incurred by the municipality itself; these distort the picture by excluding householders' costs and often the cost of flushing water), but more commonly both the institution and the individual are most concerned about the level of the capital and operating costs of the recommended program.

The objective of the financial feasibility study is to identify ways of making the alternative with the lowest economic cost affordable to the recipients. Initially, a very difficult judgment will have to be made on what proportion of their cash income householders are able and willing to devote to sanitation, and on the extent to which they can contribute their own labor and materials to reduce capital and operating costs.

For example, if on the one hand the household contribution is equivalent to the annuitized financial cost of the system, then the alternative is affordable provided that some means can be found to even out the lumpiness of the investment. This may be done by the municipality lending the funds directly to the users, by the national government channeling funds through the implementing agency, or by any other means that can be devised to fit the circumstances. If, on the other hand, it is evident that the maximum likely household contribution will not meet the annuitized cost of even the cheapest technology, then there are only two choices: abandon the program in that particular area or find means of subsidizing it through other revenues. Subsidies should be generated within the community (if possible within the sector, e.g., from water revenues to sanitation) since it is the community that primarily benefits from the improved health of its poorest members. In many small towns in developing countries, however, the tax base is too weak to sustain any further burdens. In such cases the national government may be able to provide subsidies.

Other Factors

Complementary Investments

Sullage disposal facilities need to be considered where water use exceeds, say, 50 liters per capita daily in medium- or high-density areas for all technologies except sewered PF toilets and cistern-flush toilets with conventional sewerage or septic tanks and soakaways. Off-site night-soil or sewage treatment works are required for vault toilets, sewered PF toilets, and conventional sewerage systems.

Reuse Potential

DVC toilets should be provided only where there is a demand to reuse excreta. Material from latrines can be applied as fertilizer if the pits from which it was removed were not used for 12 months or more. Sludge from sewered systems requiring periodic desludging, vault toilets, single-pit PF and VIP latrines, and conventional sewerage also can be used as fertilizer, but only after composting or treatment. Before the predicted benefits from a reuse scheme are included in the economic assessment of a technology, however, the feasibility of the scheme must be thoroughly and realistically examined, especially in areas where excreta reuse is not a traditional practice.

Self-help Potential

The unskilled labor and some (but not all) of the skilled labor required for VIP latrines, ROECs, DVC and PF toilets, and three-stage septic tanks can be provided by the users. Self-help labor, however, requires organization and supervision by the local authority, especially in urban areas. Self-help labor should be shadow priced at the opportunity cost of unskilled labor during the season when the work will be done.

Anal Cleansing Material

PF and cistern-flush toilets cannot easily cope with anal cleansing materials such as maize cobs, stones, and cement-bag paper because of the clogging of the water seal. Aquaprivies (and latrines with mechanical seals) are better able to process these materials, but at greater cost and higher risk of system malfunction than PF toilets (see chapter 8, section 5). The practice of using water for anal cleaning presents problems only to DVC toilets, which may become too wet for efficient composting.

Table 5-2. Summary of Annual Economic Costs per Household (1978 US$)

Sanitation technology	Cost Mean	 Highest	 Lowest
Pit latrines, PF toilets, and ROECs	28	56	8
DFC toilets	46	75	29
Vault and vacuum collection	104	210	26
Sewered aquaprivy or PF toilets	159	191	125
Flush toilets with septic tanks	233	390	35
Conventional sewerage	400	641	142

Note: Costs include annuitized capital and annual operating costs of on-site, collection and treatment facilities, shadow priced as appropriate. Sewerage costs are average incremental costs. The figures given in this Table are taken from a limited number of observations only (particularly in the cases of DVC toilets and sewered aquaprivies) and PF); they should therefore be used as an indication of relative costs rather than for their absolute value.

Environmental Factors Affecting Technology Choice

Information on the natural physical environment of an area will often enable one to exclude certain options. Volume 1 of this report series includes descriptions of environmental variables and their effects. Winter temperatures affect performance of waste treatment ponds, digesters, and biogas units because each decrease of about 10^{o}C (18^{o}F) results in decreasing biochemical reaction rates by half. The magnitude and rate of precipitation affects the general levels of flooding, runoff, water table, and plant growth. In contrast to the regional or global environmental influences, local changes in land use are often the limiting factor, especially in urban areas. For example, sewered communal latrines would occupy up to 3 percent of total land area where population densities are about 1,000 per hectare and up to 10 percent if shower and laundry facilities are provided (not including space for clotheslines). Other schemes may require even greater percentages of the available space.

Institutional Constraints

Sanitation technologies may not operate satisfactorily, even if they are properly designed, due to lack of adequate maintenance (at the user and/or municipal levels) because the users and some municipal officials may not be fully aware of the need for maintenance or may lack the funds or know-how to provide it. Thus, user education and institutional development programs will generally form an essential part of sanitation program planning. Often major changes are needed in a community's attitude toward excreta disposal and environmental sanitation generally, and major alterations to the existing municipal structure are often required. These changes, especially those in social attitudes, can be accomplished only slowly, which emphasizes the need for a planned series of incremental sanitation improvements over time (chapters 3 and 7). In addition, pricing policies for communal sanitation systems must provide adequate funds for maintenance expenses. If community members are able but not willing to pay the necessary rates on a continuing basis, the system should not be built.

CHAPTER 6

SANITATION TECHNOLOGY SELECTION

Once different sanitation technologies have been compared on a technical basis (chapter 5), the sanitation program planner must select from those available the one most appropriate to the needs and resources of the community. This selection, which should be based on a combination of economic, technical, and social criteria, essentially reduces to the question: which is the cheapest, technically feasible technology that the users can afford and maintain, prefer to cheaper alternatives, and the local authority is institutionally capable of operating? The critical information items needed for selection and design of sanitation systems are indicated on Table 6-1.

Selection Algorithm

Figures 6-1, 6-2, and 6-3 present algorithms that can be used as a guide to the selection of the most appropriate sanitation technology for any given community in developing countries. It should be stressed that the algorithm is meant only as a guide to the decision-making process. Its main virtue is that it prompts engineers and planners to ask the right sort of questions, which perhaps they would not otherwise ask; some answers can only be obtained from the intended beneficiaries (chapter 3).

The algorithm commences in Figure 6-1 by asking if there is (or is likely to be in the near future) an in-house level of water supply service to the houses under consideration. This is the key question as its answer immediately determines whether cistern-flush toilets can be considered. If the houses do have piped water, if there is a strong social desire for cistern-flush toilets, and if they can be afforded, the main engineering problem is how to dispose of the wastewater. If neither septic tanks nor conventional sewerage is affordable, or if the community does not have an in-house water supply service, then cistern-flush toilets cannot be used.

If the quantity of water available is not sufficient for several systems, the choice lies between the various on-site excreta disposal technologies, with appropriate facilities for the disposal of sullage (chapter 10). The algorithm recommences in Figure 6-2 by asking if household reuse of excreta is socially acceptable. If it is, then the choice is between three-stage septic tanks and double-vault composting toilets. Reuse of liquid excreta from three-stage septic tank systems is appropriate for rural areas only, whereas DVC toilets are suitable for urban areas as well, provided that there is space for them and that the users are able and willing to reuse the compost in their own gardens or are able to give or sell it to local farmers.

If DVC toilets and the three-stage septic tank system cannot be used, the choice lies among VIP latrines, VIDP latrines, ROECs, PF toilets, vault toilets, and communal sanitation blocks as determined by the algorithm in Figure 6-3. If there is space enough for two alternating pit sites and if the groundwater table is at least 1 meter below the ground surface, then the recommended choice is either VIP latrines, VIDP latrines, ROECs or, if there is sufficient water and if the soil is sufficiently permeable, PF toilets. As the costs of these systems are very similar, the choice among them should be left to the community.

TABLE 6-1

CRITICAL INFORMATION ITEMS NEEDED FOR SELECTION AND DESIGN OF SANITATION SYSTEMS

Climatic conditions

Temperature ranges; precipitation, including drought or flood periods.

Site conditions

Topography.
Geology, including soil stability.
Hydrogeology, including seasonal water table fluctuations.
Vulnerability to flooding.

Population

Number, present and projected.
Density, including growth patterns.
Housing types, including occupancy rates and tenure patterns.
Health status of all age groups.
Income levels.
Locally available skills (managerial and technical)
Locally available materials and components.
Municipal services available, including roads, power.

Environmental sanitation

Existing water supply service levels, including accessability and reliability, and costs.
Marginal costs of improvements to water supply.
Existing excreta disposal, sullage removal and storm drainage facilities.
Other environmental problems such as garbage or animal wastes.

Socio-cultural factors

People's perceptions of present situation and interest in or susceptibility to change.
Reasons for acceptance/rejection of any previous attempts at upgrading.
Level of hygiene education.
Religious or cultural factors affecting hygiene practices and technology choice.
Location or use of facilities by both sexes and all age groups.
Attitudes towards resource reclamation.
Attitudes towards communal or shared facilities.

Institutional framework

Allocation of responsibility, and effectiveness of state, local or municipal institutions, in providing the following services:
  Water
  Sewerage, Sanitation, Street cleansing, Drainage
  Health
  Education
  Housing and urban upgrading

Note: The priority between various items will vary with the sanitation options being considered; the list above indicates typical areas which should be investigated by planners and designers.

In those urban areas where VIP latrines, ROECs and unsewered PF toilets cannot be used, the choice is between vault toilets and communal facilities. Vaults are preferable to communal facilities but they are more expensive and require access for collection vehicles, which the municipality must be capable of maintaining. In a few very high density areas there may not be access for even the smallest collection vehicles. In such areas either communal sanitation facilities are necessary or the vaults must be emptied by manually operated pumps, but it should be pointed out that the community may prefer the latter approach because it is an in-house facility and one which has good potential for upgrading to a sewered PF system (Chapter 7). However there are some high density/low income urban areas, such as those built on tidal mudflats, for which a sewered PF system will always remain unaffordable, though be technically feasible, and a communal facility is the only realistic sanitation improvement. Further improvement will generally be extremely difficult and often impossible both technically and economically, unless it forms part of an urban renewal scheme involving overall housing improvements.

Post-selection Questions

Once a tentative selection of the most appropriate technology has been made, several questions should be asked again as checks. These are:

(1) Is the technology socially acceptable? Is it compatible with cultural and religious requirements? Can it be maintained by the user and, if appropriate, by the municipality? Are municipal support services (e.g. educational, inspectional) required? Can they be made available?

(2) Is the technology politically acceptable?

(3) Are the beneficiaries willing (as well as able) to pay the full cost of the proposed facility? If not, are user subsidies (direct grants or "soft" loans) available? Is foreign exchange required? If so, is it available?

(4) What is the expected upgrading sequence (see Chapter 10)? What time frame is involved? Is it compatible with current housing and water development plans? Are more costly technologies in the upgrading sequence affordable now?

(5) What facilities exist to produce the hardware required for the technology? If lacking, can they be developed? Are the necessary raw materials locally available? Can self-help labor be used? Are training programs required?

(6) Can the existing sanitation system, if any, be upgraded in any better way than that shown in the algorithm?

(7) Is there a neighboring area whose existing or planned sanitation system makes a more costly alternative feasible? (e.g. small sewers discharging to an existing sewer system).

(8) What is the potential for reuse? If low, would the adoption of a technology with a higher reuse potential be economically justifiable?

(9) If the selected technology cannot deal with sullage, what facilities for sullage disposal are required? Is the amount of sullage water low enough, or could it be reduced sufficiently, to preclude the need for sullage disposal facilities?

Figure 6–1. First-stage Algorithm for Selection of Sanitation Technology

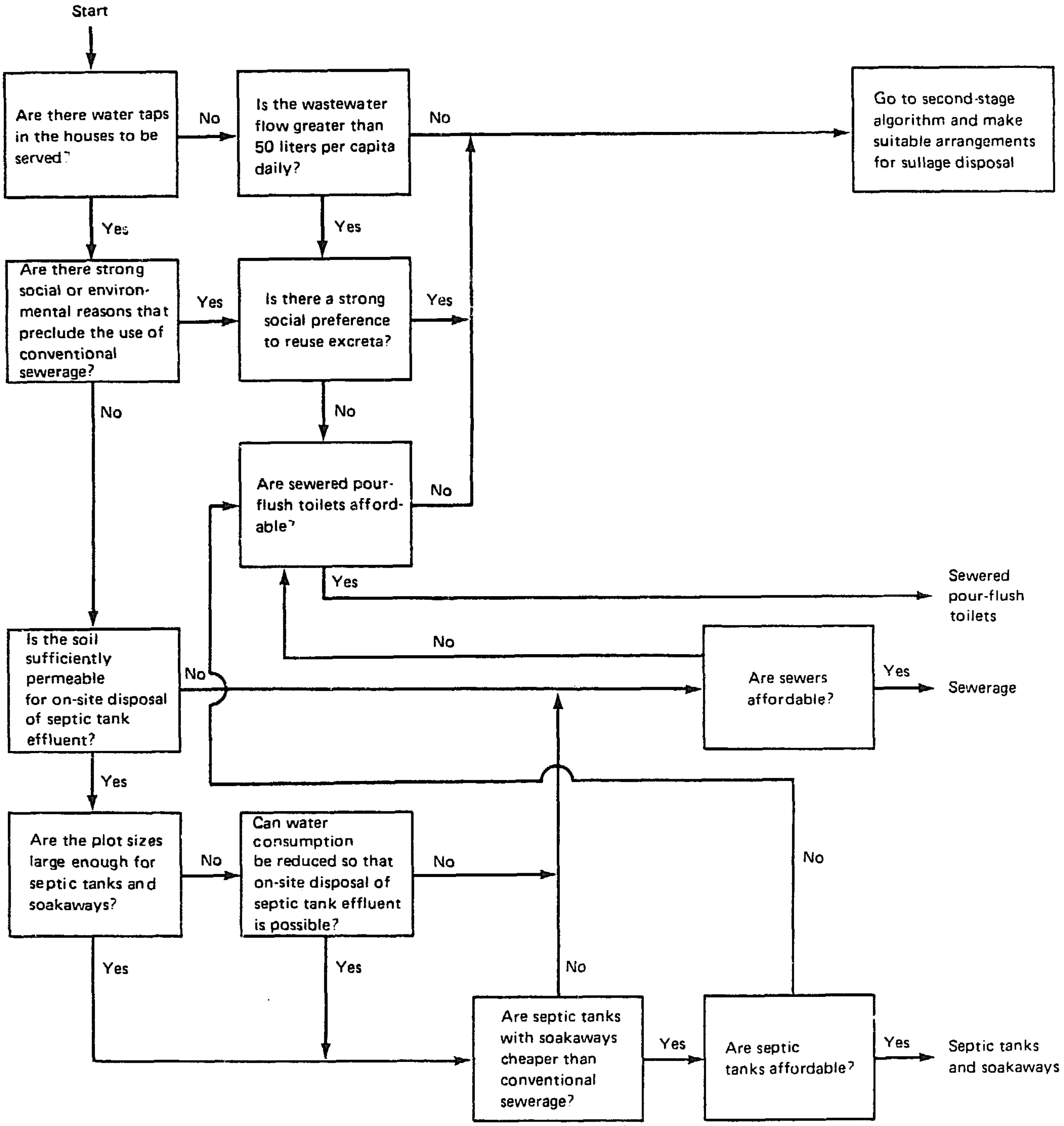


Figure 6–2. Second-stage Algorithm for Selection of Sanitation Technology

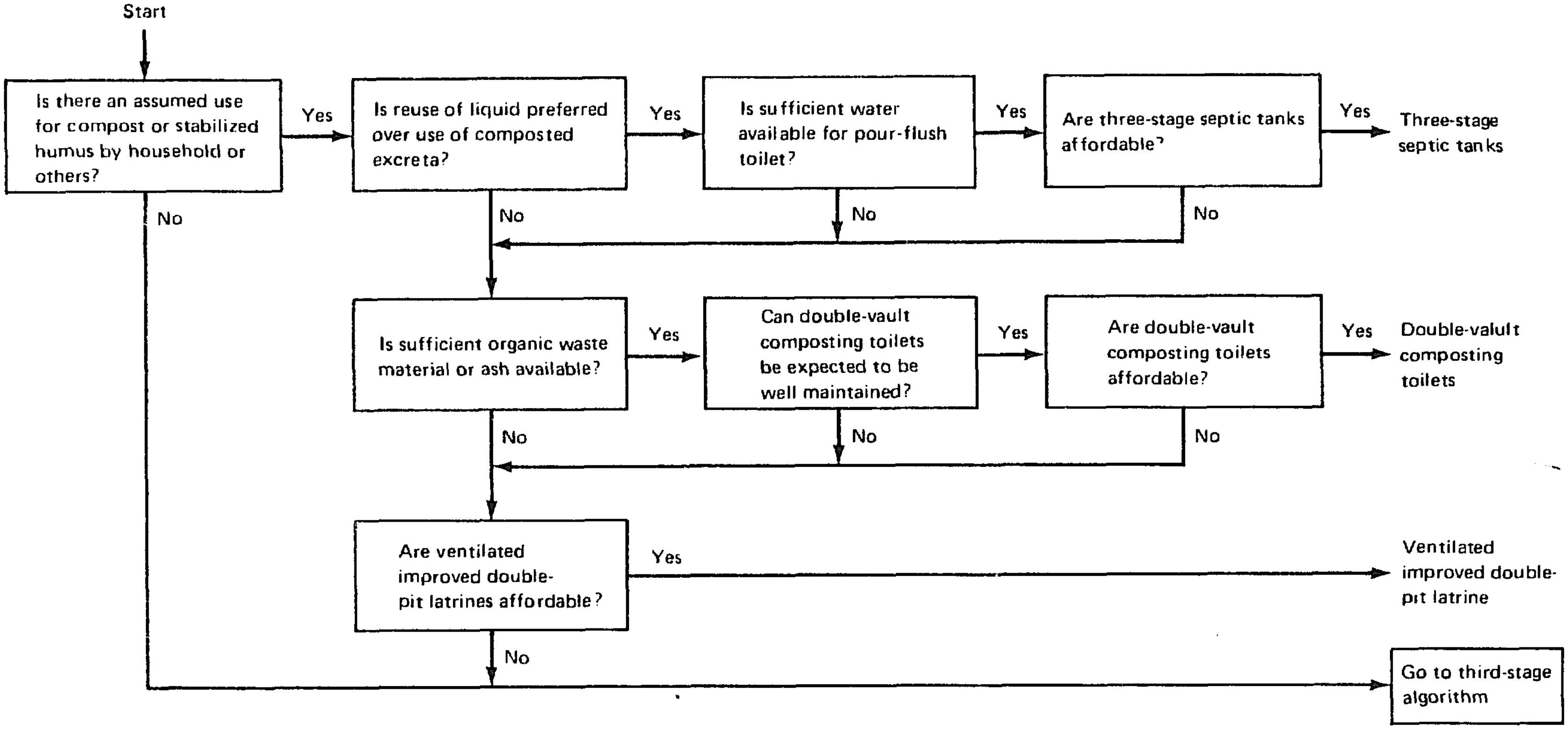
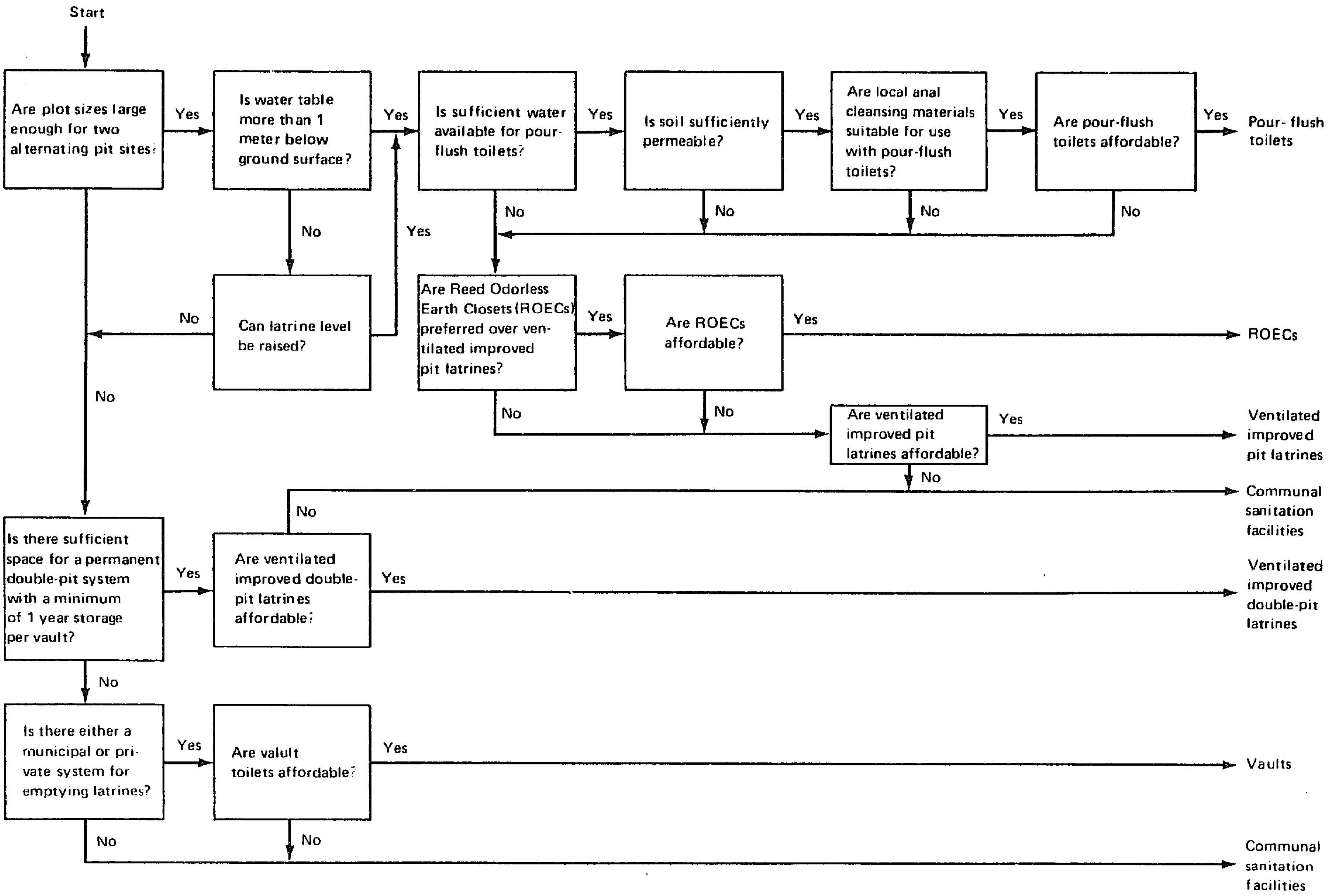


Figure 6–3. Third-stage Algorithm for Selection of Sanitation Technology



CHAPTER 7

SANITATION UPGRADING SEQUENCES

The selection of the technology best suited to effect initial improvements in sanitation has been discussed in chapter 6. This selection should also reflect the future need for incremental improvements as the users' aspirations and socioeconomic status rise. This chapter examines the feasibility of sanitation upgrading sequences with particular reference to incremental improvements in the level of water supply service (which is, of course, a measure of socioeconomic status). Feasible upgrading sequences are summarized in Figure 7-1 and described below. It should be noted that upgrading is optional and should be done only if user demand and ability to pay for additional investments exists or where environmental conditions (increased population density, and the like) require it.

Composting Toilets

Provided that the toilet functions well and is properly operated and that the demand for compost continues, there is no need to upgrade the toilet. If the demand for compost should fall (due perhaps to increased housing density necessitating fewer gardens or the introduction of subsidized chemical fertilizer distribution) or the toilet does not function properly (due perhaps to a sudden or a gradual unavailability of ash or suitable waste organic material), then it would be necessary to alter (rather than upgrade) the toilet; the most appropriate replacement technology will normally be the VIDP, which would not require a change in anal cleansing materials, or the PF toilets and thence, eventually, to a sewered PF system. The user may also wish to make this change as an upgrading of his facility as a personal choice rather than being forced to do so by changing conditions.

Three-Stage Septic Tank

This version of the septic tank is suitable where PF toilets are installed and excreta reused as fertilizer in liquid form, as for example in many rural areas of China. Upgrading would apply only to water supply service level.

If the demand for liquid excreta to be reused as fertilizer falls, it is necessary to alter the technology rather than upgrade it although, as in the case of the DVC, the user may select to do this as a personal choice. The easiest modification in rural areas is subsurface percolation in a septic tank drainfield; sullage may then be added to the third compartment, as described in chapter 8, section 1).

Vault Toilets

No upgrading is necessary from the point of view of excreta disposal. Since the water supply service improves to the multiple tap level, however, it may be considered desirable to provide sewers for sullage disposal. If sewers are installed, the vault toilet may be readily converted to a sewered PF toilet.

VIP Latrines and ROECs

Many rural and suburban water and sanitation projects aim at providing pit latrines and communal hand-pumps or public standposts as the initial improvement. The pit latrine should be either a VIP latrine or ROEC, as described in chapter 8, section 3. The subsequent priority for improvement would most likely be upgrading the water supply to yard taps (or household hand pumps where applicable). Both the VIP latrines and ROECs could then be upgraded to pour-flush toilets. With both VIP latrines and ROECs it is helpful if the original design permits easy removal of the squatting plate to facilitate its replacement by a water-seal unit.

It should be noted that in many areas, especially where water is used for anal cleansing, users prefer a PF toilet even though water has to be carried to the house. In such cases, a water storage vessel near the toilet should be provided.

PF Toilets

When the water supply is upgraded to the multiple tap level, it is possible to install a low-volume cistern-flush toilet. This is not essential and may not be considered a priority by the users, to whom upgrading of the water supply from a single yard tap to multiple in-house connections usually first means plumbed kitchens and bathrooms.

As discussed above for vault toilets, the main sanitation improvement is better sullage disposal. If sewers are to be used, they can also receive the settled flushwater from the original PF pit. The conversion operation is as follows:

(1) build a small single-chamber septic tank close to the existing PF pit and discharge all the sullage directly into it (the tank should provide 12 hours retention time, subject to a minimum working volume of 0.5 cubic meter);

(2) connect the existing PF pit to the sullage tank with 100-millimeter-diameter pipe (the pit outlet "t" junction should be located as near the top of the pit as technically feasible); and

(3) connect the sullage tank to the street sewer (the invert of the tank outlet should be a nominal 30 millimeters below that of the inlet from the pit to prevent sullage flowing into the pit).

If the existing pit has sufficient infiltration capacity there will be little or no flow from the pit to the sullage tank. This does not matter. But as the infiltration capacity falls, and especially if low-volume cistern-flush toilets are installed, the flow will increase, and the pit acts as a sealed or semisealed first compartment of the two-stage septic tank described in chapter 8, section 5. It is essential that the sullage tank--the second compartment of the two-stage septic tank--is provided so that the small-bore sewers do not become blocked.

Sample Staged Solutions

To demonstrate the feasibility of using a staged sanitation system, a possible scheme with several variations is described, and comparative economic costs are presented. The scheme or its variations could be started at any stage and terminated at any stage, depending on the desires of the users. For simplicity it is assumed that each stage remains in service for 10 years, when the next stage would be added. The schemes described could be varied substantially without adding greatly to the cost. For example, to a PF latrine, a vault (with vacuum-truck emptying) could be added if housing density increases or the soil becomes clogged. Similarly, a composting toilet that already has a watertight vault could be converted into a vault toilet or PF privy with a vault.

As shown in Figure 7-2, the initial sanitation facility would consist of a VIP latrine with a concrete squatting slab and concrete block superstructure. One such facility in an East African city is used as the basis for the costs shown. Its (unlined) pit is about 5 1/2 meters deep and 1 meter square, and the normal filling time is 10 years. [1] Its initial construction cost is $108, of which the superstructure accounts for $53.

In year 11 the community water system is upgraded from wells or standposts to yard hydrants, and the dry latrine is converted to a pour-flush latrine by digging a new soakage pit near the superstructure and replacing the old squatplate with a bowl and inverted siphon. The old pit is filled in prior to placement of the new squatplate. For estimating purposes it is assumed that the accumulated sludge would be removed from the new pit at 5-year intervals and composted. [2] The cost of trucks and the land and equipment for the composting facility are therefore included in year 15, and the trucks are replaced at 5-year intervals thereafter. The operating and maintenance costs incurred in years 11-20 also include the flushing water for the PF calculated as 10 liters per capita daily for six persons at $0.35 per cubic meter.

In year 21 the third stage would begin when the water service is upgraded to house connections and a large volume of sullage water has to be disposed of. At this point a new (lined) pit would be dug and the existing bowl and siphon would be connected to it. An overflow pipe would connect the pit to a newly constructed small-bore sewer system (SBS). This upgrading would permit the use of cistern-flush toilets if desired by the users. Annual collection of sludge would be required from the smaller vault and two trickling filter plants would be constructed for treatment of the vault effluent. [3] The combined flushing water and sullage flow from year 21 onwards is taken as 175 liters per capita daily.

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1. Alternatively--especially where ground conditions make deep excavation difficult or expensive--two alternating pits may be constructed with the squatting plate moved to the second pit after the first is filled. The full pit can be emptied after one year and eventually reused, and the excavated material could be used without further treatment.

2. In small communities, sludge would probably be buried rather than composted.

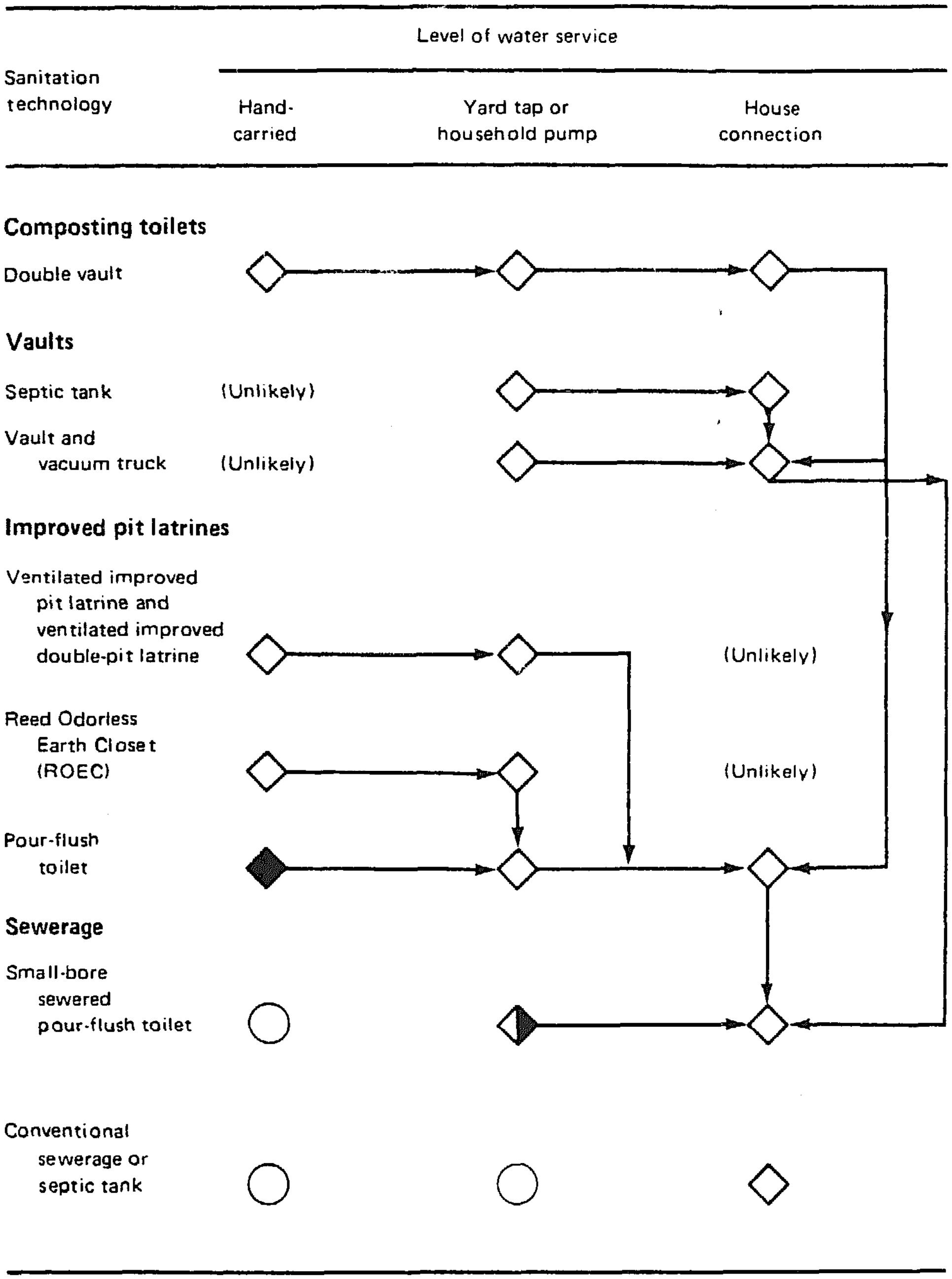
3. This option is chosen for illustrative purposes because of available cost data from the same East African city.

Comparative economic costs, on a household basis, were prepared for this scheme and for three variations, including the alternative of proceeding immediately with the construction of a conventional sewerage system. The present value of the total cost per household of the three-stage scheme over a 30-year period is $354 including the salvage value of the sewerage system, which is assumed to have a 40-year life. The second variation is a two-stage scheme that moves directly from the VIP (installed in year 1) to small-bore sewers in year 11. The present value cost per household over 30 years is $1,111, or more than three times that of the three-stage alternative. The third alternative is simply to install a small-bore sewerage system in year 1. This would have a total present value cost of $1,519 per thousand over 30 years. The final alternative, calculated in the same way and with data from the same city as the sewered PF for purposes of comparison, is the immediate construction of a conventional sewerage system (CS). A 5-year construction period is assumed. The facility is assumed to be two-thirds utilized upon completion and fully utilized 10 years after completion. Based on these assumptions the present value cost per household over 30 years is $3,000. This includes the cost of flushing water and all regular operating and maintenance costs (as do the costs of the other alternatives). It is nearly ten times as high as the cost of the three-stage scheme and almost twice that of the one-stage sewered PF alternative.

An alternative to this upgrading sequence would be to move from the VIP latrine to a vault with vacuum-truck collection (VC) in year 11. Based on costs from such a system in a city in Taiwan, the total present value cost per household over 30 years would be $334. If in year 21 it was decided to convert from vacuum collection to a small-bore sewer system (as described in the previous sequence) the total present value cost would increase to $411 per household. These costs are summarized in Table 7-1, where the figures in parentheses represent construction costs in years 1, 11, and 21.

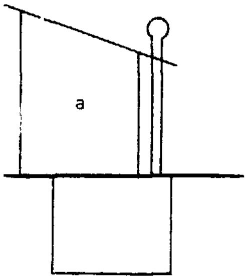
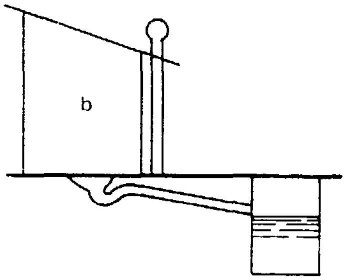
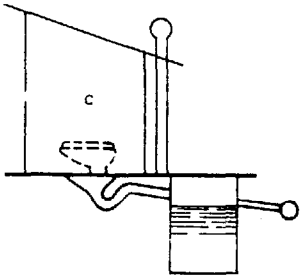
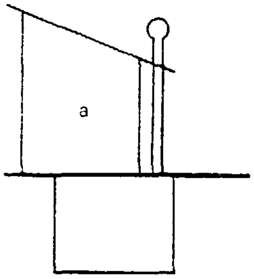
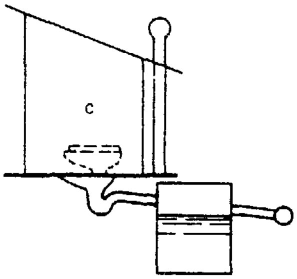
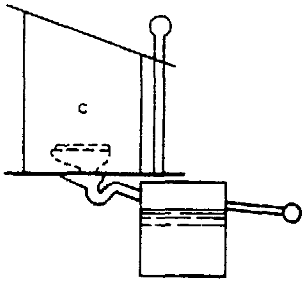
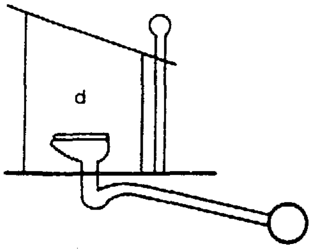
It is noteworthy that none of the upgrading sequences discussed above leads to conventional sewerage. This is not because conventional sewerage schemes should not be built (they are an excellent form of sanitation for those who can afford them and have plenty of water), but because they are not necessary to provide the highest standard of sanitation. The sewered PF system, which can include a low-volume cistern-flush toilet for added user convenience, is an equally high standard sanitation system that has two big advantages over conventional sewerage: it is substantially cheaper and it can be reached by staged improvement of several different sanitation technologies. Thus sanitation program planners can confidently select one of these "baseline" technologies in the knowledge that, as socioeconomic status and sullage flows increase, it can be upgraded in a known sequence of incremental improvements to a sophisticated final solution. The important fact to remember is that sewers are required to dispose of sullage, not excreta, and that the elimination or reduction of nonessential water use is thus the key element in an economic solution to sanitation problems. This is particularly significant in developing countries where the increasing competition for investment funds often limits the amount of resources that can be allocated to the water and sanitation sector.

Figure 7–1. Potential Sanitation Sequences



◇ , 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.

Figure 7–2. Sample Sanitation Sequences (cost data in 1978 U.S. dollars)

Item	Year 1	Year 10	Year 20	Year 30	Total economic cost per household 30-year period
Scheme 1					
Construction cost	108	65	905		354
Scheme 2					
Construction cost	108	915			1,111
Scheme 3					
Construction cost	960				1,519
Scheme 4					
Construction cost	978				3,000

a, Ventilated improved pit latrine; b, pour-flush toilet with soakaway; c, pour-flush toilet with small-bore sewer (with optional bowl and seat); d, conventional sewerage.

CHAPTER 8

ON-SITE TECHNOLOGIES

8.1 Latrine and Toilet Superstructures

The function of the toilet superstructure is to provide privacy and to protect the user and the toilet from the weather. Superstructure design requires assessment of whether separate facilities are required for men and women in the same household. Local customs and preferences often influence its location, orientation, shape, construction material, design (e.g., without roof, window details), and size. Color may be very important to householder use and maintenance of the facility. These details should be designed in consultation with the user. The technical design requirements of the superstructure are relatively straightforward and may be stated as follows:

(1) Size: the plan area should be at least 0.8 cubic meter to provide sufficient space and generally not more than 1.5 cubic meters. The roof height should be a minimum of 1.8 meters.

(2) Ventilation: there should be several openings at the top of the walls to dissipate odors and, in the case of VIP latrines and ROECs, to provide the through draft required for functioning of the vent pipe. These openings should be about 75 to 100 millimeters x 150 to 200 millimeters in size; often it is convenient to leave an open space between the top of the door and the roof.

(3) The door: this should open outwards in order to minimize the internal floor area. In some societies, however, an outward opening door may be culturally unacceptable, and an open entrance with a privacy wall may be preferred. In either case it must be possible to fasten the door from the inside, and it may also be necessary to provide an external lock to prevent use by unauthorized persons. At its base the door should be just clear of the floor in order to provide complete privacy while preventing rot of the bottom of the door planks.

(4) Lighting: natural light should be available and sufficient. The toilet should be sufficiently shaded, however, to discourage flies; this is particularly important in the case of VIP latrines and ROECs.

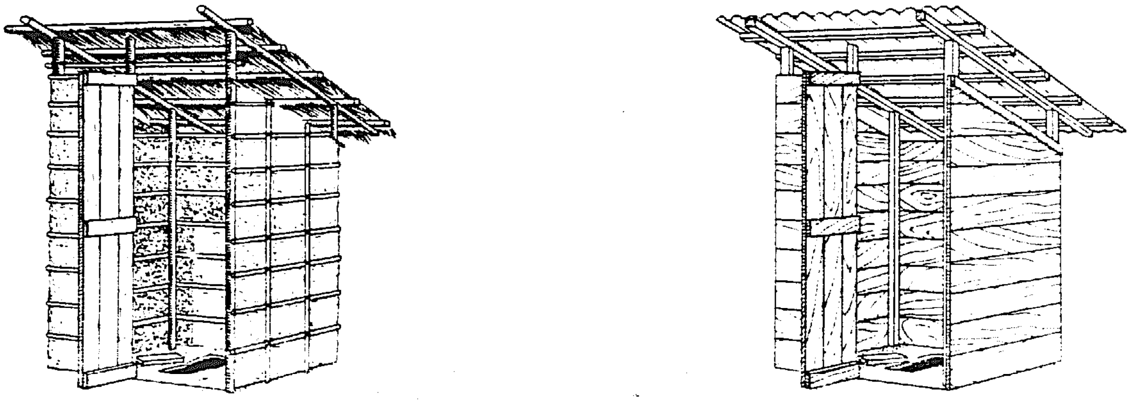
(5) The walls and roof: these must be weatherproof, provide adequate privacy, exclude vermin, and be architecturally compatible in external appearance with the main house. In urban areas especially an L-shaped wall in front of the door may be regarded by the community as desirable or essential for privacy.

A wide variety of materials may be used to construct the superstructure, for example: brick or concrete blocks, with tile or corrugated iron or asbestos cement roof; mud and wattle, bamboo or palm thatch, with palm thatch roof; ferrocement, sheet metal, or timber with corrugated iron or asbestos cement roof. Some alternatives are illustrated in Figure 8-1. The choice depends on cost, material availability, and community preferences. The important point is that they meet the criteria (5) above. If the superstructure is for a VIP latrine or ROEC, it may not be a permanent structure but one that must be dismantled and re-erected over or adjacent to the new pit. It should therefore be designed with this in mind, although this becomes of less economic importance as the design life of the pit increases.

Many communities, given the choice, opt for an inside toilet. Only PF and cistern-flush toilets are suitable for interior locations. If these are not to be provided initially, it may be sensible to design the house with a toilet compartment that can be fitted out at a later date as part of a sanitation upgrading program.

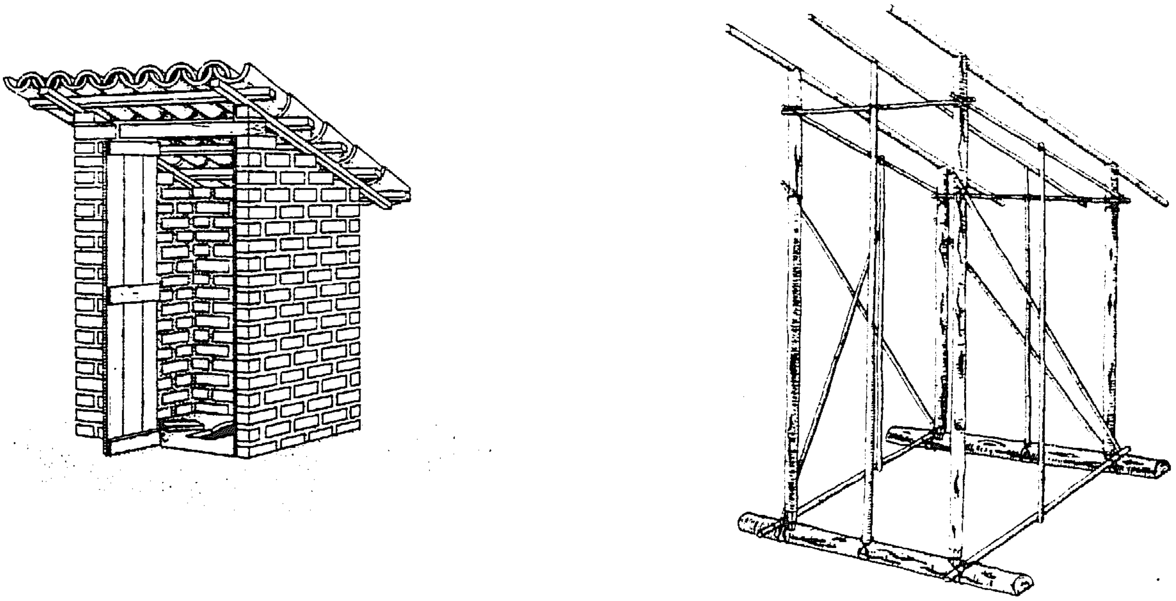
In Figure 8-1, several low-cost, easily constructed superstructures are shown. A wide variety of options is available to the homeowner, only four of which are illustrated here. The choice of superstructure should reflect the users personal preferences.

Figure 8–1. Alternative Materials for Latrine Superstructures
Part A.



A. Mud and wattle walls and palm thatch roof

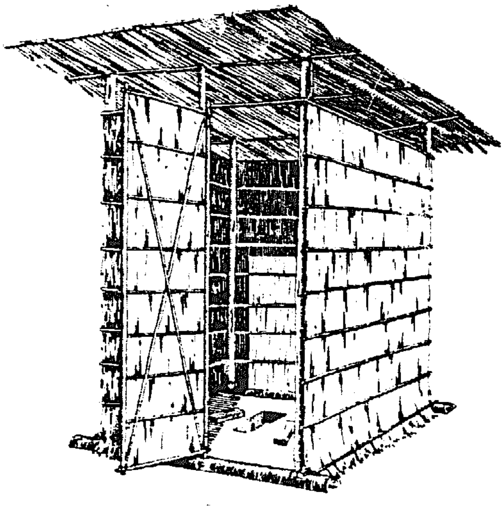
B. Timber walls and corrugated iron or asbestos-cement roof



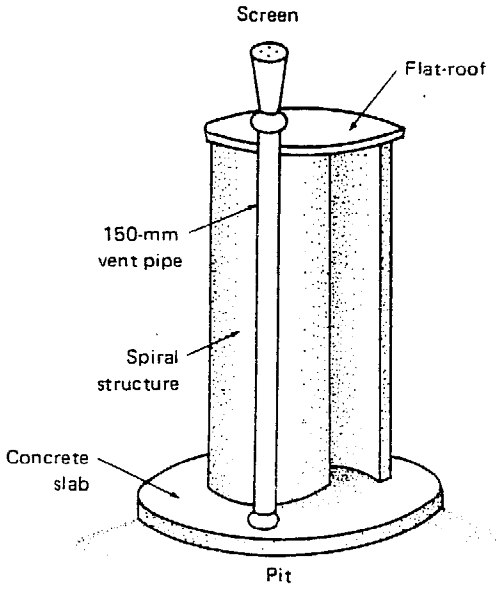
C. Brick walls and tile roof (an alternative is concrete block walls and corrugated iron or asbestos-cement roof)

D. Rough-cut tree limbs and logs

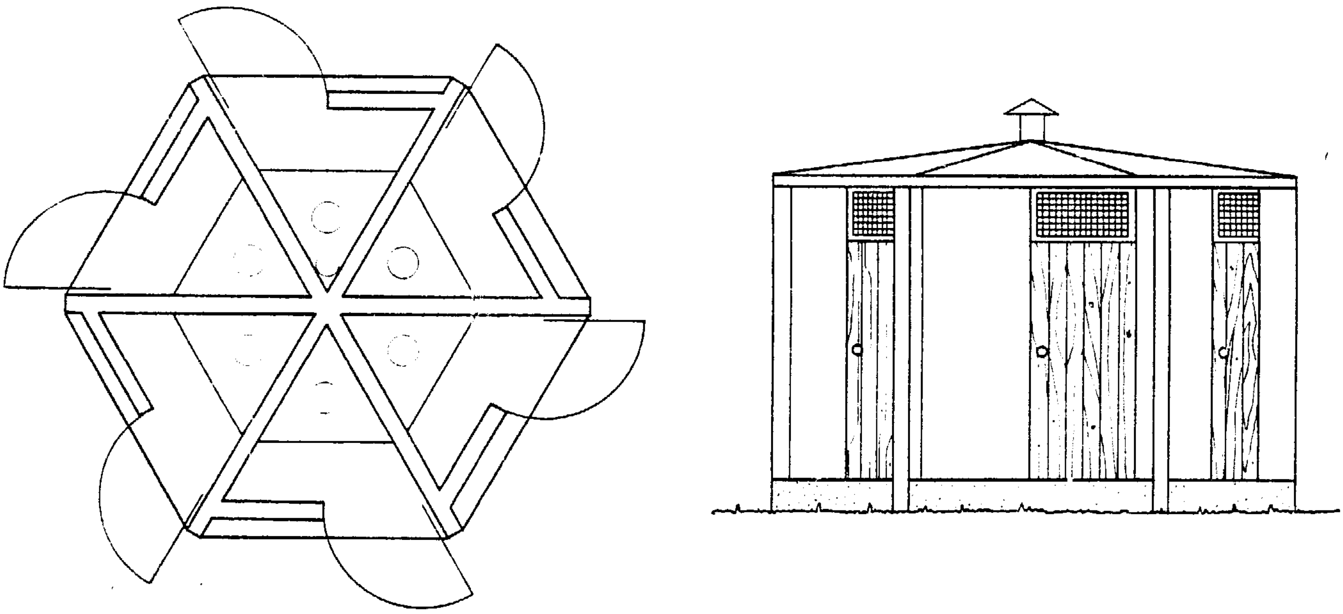
Figure 8–1 (Continued)
Part B.



E. Palm thatch wall and roof covering



F. A ventilated pit privy



Plan

Elevation

G. Multiple-compartment Pit Latrine

Source: Part A, Wagner and Lanoix (1958).
Part B: E, Wagner and Lanoix (1958): F, Appropriate Technology (Vol. 6 No. 3, November 1979):
G, Adapted from a design used by the foundation or Cooperative housing in Haiti.

8.2 Latrine and Toilet Fixtures

A suitable base or foundation for latrine or toilet fixtures is often included in the construction of the pit or other substructures. Alternatively, the base may be constructed separately of wood or integrally as part of the squatting plate.

It is essential to determine whether the local preference is to sit or squat during defecation. If the wrong facility is chosen, it will have to be converted at unnecessary expense; alternatively, it will remain unused or the superstructure will be used for other purposes such as grain storage. Anal cleansing practices and materials also need to be evaluated; flap-trap designs, conventional and VIP latrines, ROECs, and aquaprivies can accept rocks, mud balls, maize cobs, and other bulky materials that would clog water seals.

Squatting Plates for VIP Latrines

Four important design considerations (for further details, see chapter 8, section 3) are:

(1) The opening should be about 400 millimeters long, to prevent soiling of the squatting plate, and at most 200 millimeters wide, to prevent children falling into the pit. A "keyhole" shape is suitable.

(2) Footrests should be provided as an integral part of the squatting plate and properly located so that excreta fall into the pit and not onto the squatting plate itself.

(3) The free distance from the back wall of the superstructure to the opening in the squatting plate should be in the range of 100 to 200 millimeters; if it is less there is insufficient space, and if it is more there is the danger that the rear part of the squatting plate will be soiled. Generally, the preferred distance is 150 millimeters.

(4) The squatting plate should have no sharp edges to make its cleaning difficult and unpleasant.

A variety of materials can be used to make the squatting plate: timber, reinforced concrete, ferrocement, and sulfur cement are usually the cheapest; but glass reinforced plastic, high-density molded rubber, or PVC and ceramics can also be used. Cost and aesthetics are the important criteria, apart from strength and rigidity. A variety of finishes can be applied to concrete or ferrocement squatting plates (for example, alkali-resistant gloss paint and polished marble chippings) or the concrete itself can be colored. Aesthetic considerations are often extremely important to the users and should never be ignored by engineers and planners; indeed, they should make a special effort to determine community preferences before the final design stage.

Figure 8-2 shows a good design for a reinforced concrete squatting plate. A ferrocement version of this is possible and advantageous since it need only be 1.8 to 25 millimeters thick, rather than 70 millimeters as own, with consequent savings in materials and weight but with equal strength. e mix specification for ferrocement is: 1 part cement, two parts medium coarse sand, and 0.4 parts water; reinforcement is provided by two layers 12-millimeter-opening chicken wire across the slab. An alternative rrocement design with an integral metal "flap-trap" has been developed in nzania (Figure 8-3). The metal flap-trap is prefabricated from 1-millimeter-ick mild steel sheet and then galvanized. It is not known how successful is design is; Figure 8-3 is included to demonstrate the feasibility of veloping locally acceptable alternatives.

Squatting plates should be cast in an oiled timber mold for ease construction. If the scale of manufacture is large, a steel mold may be eferable.

uatting Plates for ROECs

With ROECs (for further details, see chapter 8, section 3) it is cessary to provide a steeply (60°) sloping chute to direct the excreta to the adjacent offset pit (Figure 8-4). The chute diameter should be 200 llimeters but should be enlarged under the squatting plate to attach ound the entire squatting plate opening. It is possible, but rather fficult, to cast the chute in ferrocement as an integral part of the atting plate; in practice it is easier to use metal or polyvinyl chloride VC) pipe cut to shape.

destal Seats for VIP Latrines and ROECs

The important design criteria (for further details, see chapter 6) e the seat height and the size of the opening. For adults a 250-millimeter ameter is normally suitable. The pedestal riser can be constructed in ick, concrete blockwood, or wood; internal surfaces of ROECS should be ooth and accessible for cleaning. To encourage proper use by children and prevent them falling into the pit, a second smaller (150-millimeter ameter) seat should be provided. This may be a separate seat on the seat ver. A cover should always be provided to minimize fly access, but it ould have several small holes drilled in it to permit the through draft cessary in these toilets for odor control. Alternative designs are shown Figure 8-4.

atting Plates for Composting Toilets

These are the same as squatting plates for VIP latrines, except t if urine is to be excluded a suitable urine drainage channel must be ovided (See chapter 8, section 4, figure 8-15.)

atting Plates for PF and Vault Toilets

Squatting plates for PF and Vault Toilets have a configuration ilar to those of VIPs. However, in lieu of a being open to the pit, the at plate opening has sloping walls terminating in a water seal unit ap). For vault toilets, the plate and trap are usually fabricated in one ce. For PF toilets with displaced pit, the trap connects to a pipe separately, the 4 squat plates placed in position after installation of trap and pipe.

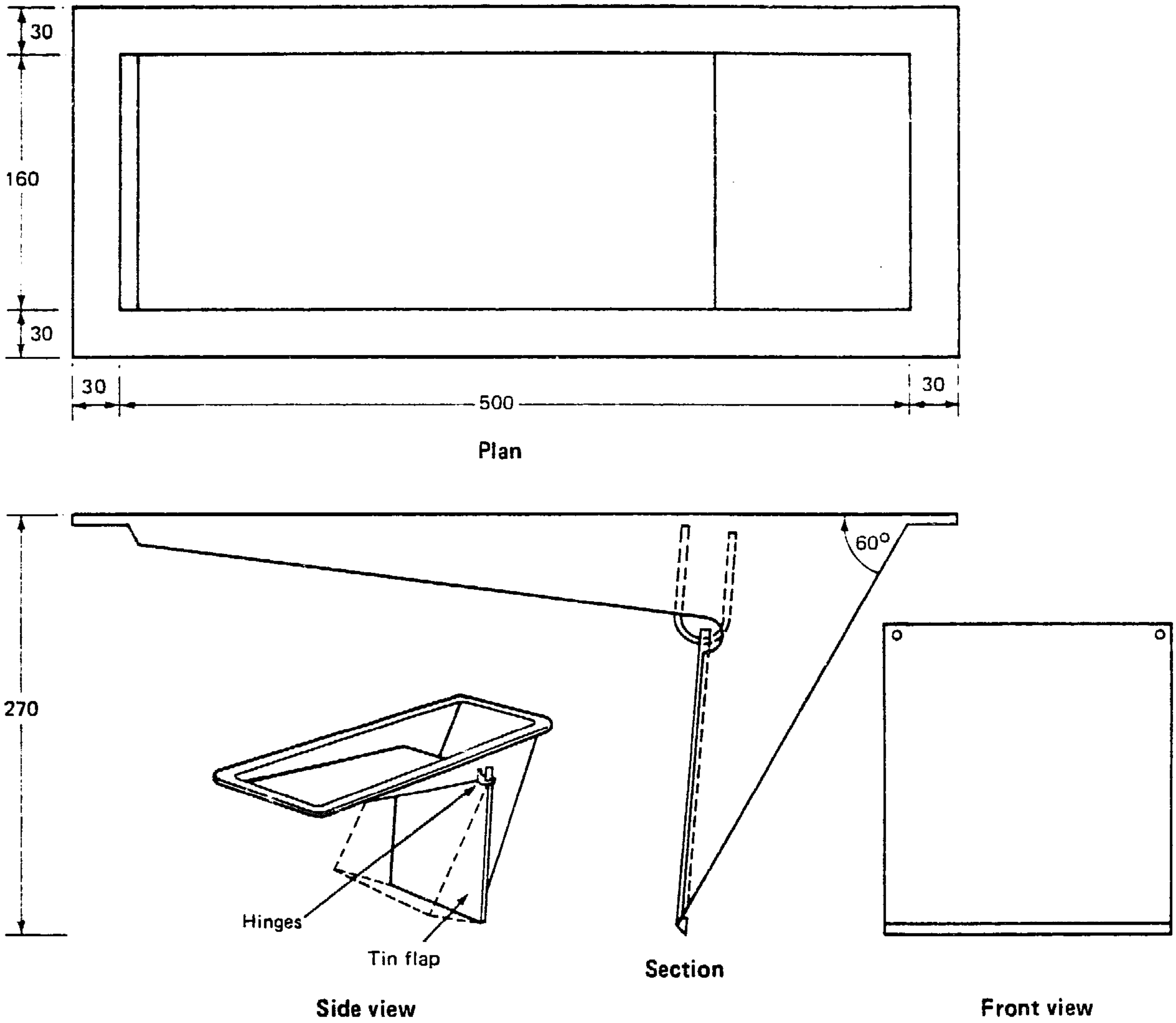
If the squatting plate is situated immediately over the pit or vault (for further details, see chapter 8, section 5 and chapter 9, section 4), the design is of the type shown in Figure 8-5. This unit is most easily made from ferrocement or reinforced plastic. An alternative sheet metal design, essentially a PF modification of the Tanzanian "flap-trap" described above, is shown in Figure 8-6. It is essential that this unit be properly and completely galvanized before it is cast into the ferrocement slab. Figure 8-7 shows a similar design that can easily be produced in plastic. When used with VIP latrines, all designs of squatting plates discharging to the pit should be placed to flush forward to avoid erosion of the pit wall.

If the squatting plate is connected to a completely displaced pit or vault, the design is of the type shown in Figure 8-8.

Pedestal Seats for PF and Vault Toilets

These are essentially the same design as for cistern-flush toilets but with a smaller water seal (generally 15 to 20 millimeters) and a smaller exposed surface area and volume of water (around 75 square centimeters and 2 liters respectively). A low-cost ceramic design like that from Colombia costs about $5 and is shown in Figure 8-8.

Figure 8-3. Tanzanian "Flap-trap" Design for Ventilated Improved Pit Latrines and Double-vault Composting Toilets (millimeters)



Plan

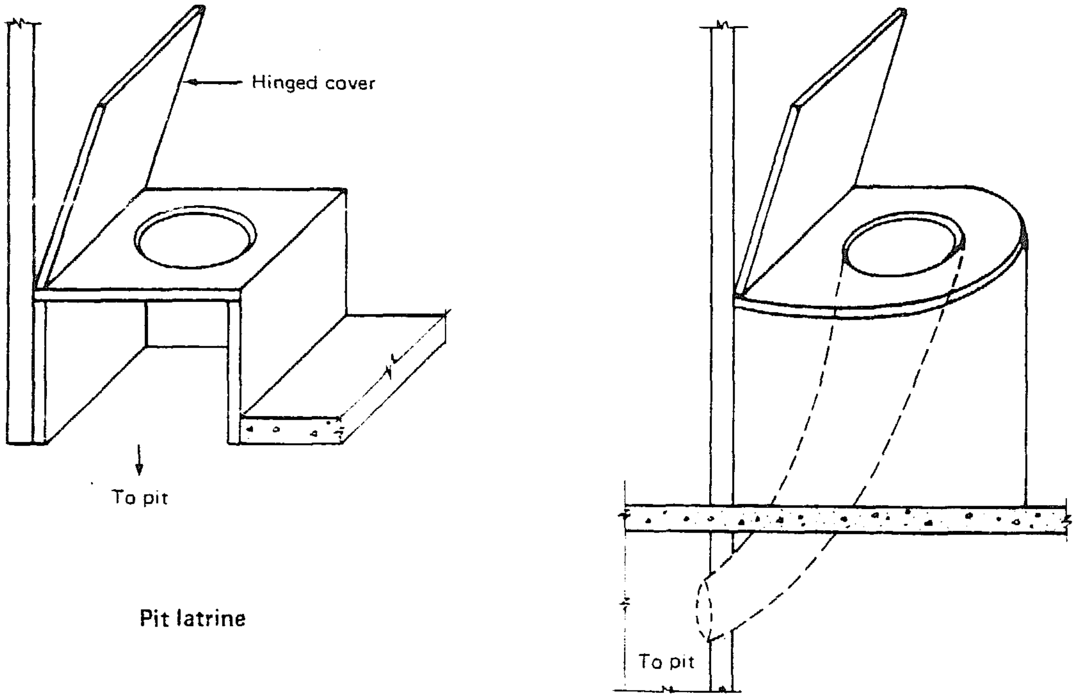
Side view

Section

Front view

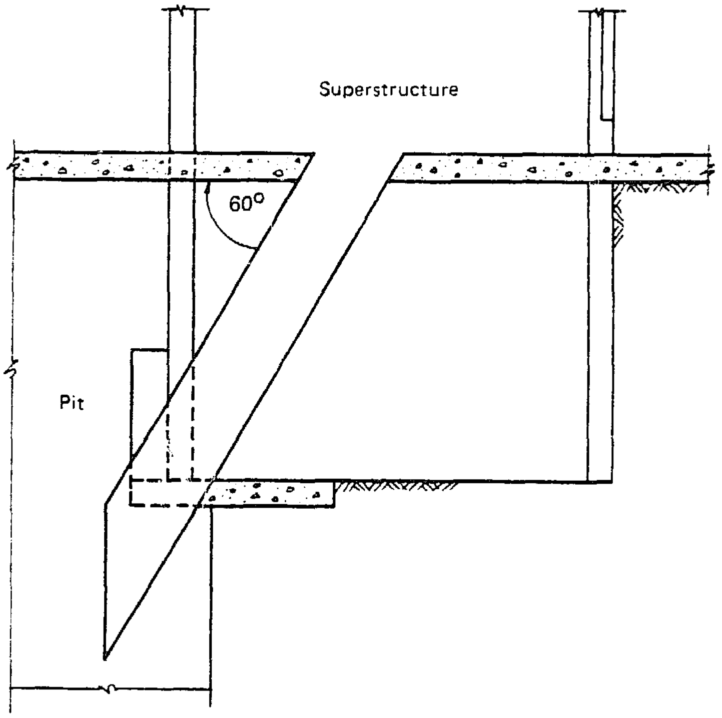
Source: Adapted from a drawing by U. Winblad.

Figure 8-4. Pedestal Seats for Dry Latrines and Chute Designs for ROECs



Pit latrine

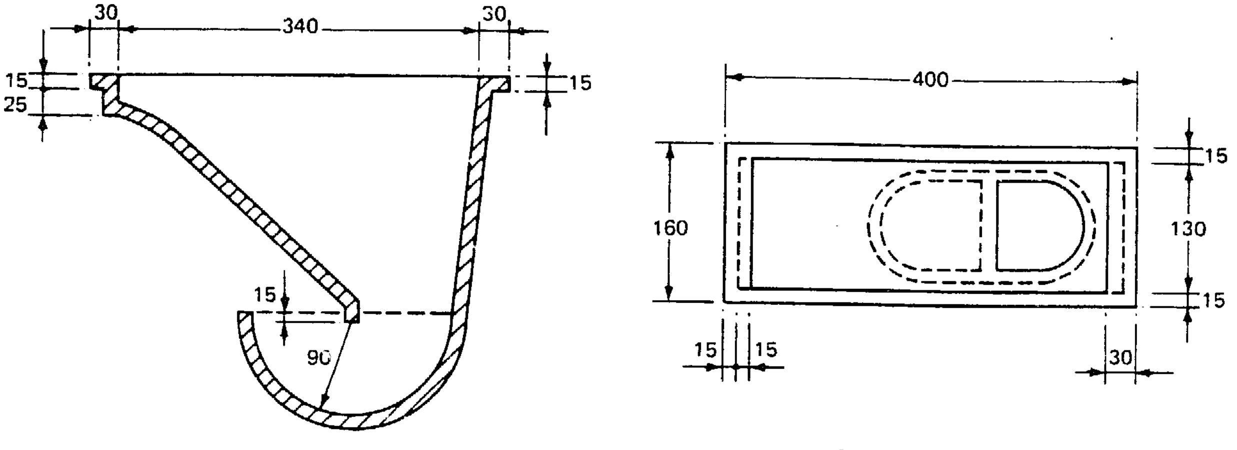
Reed Oderless Earth Closet (ROEC)



Squatting chute

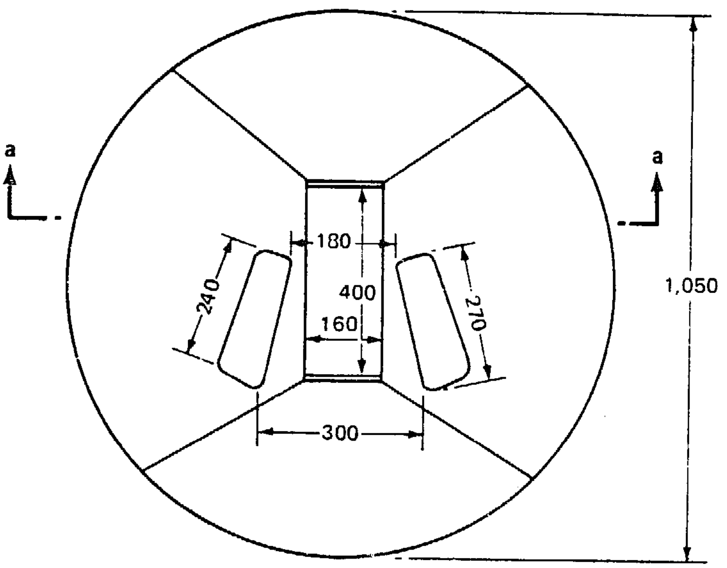
Note: The pedestal hole should be 100 millimeters in diameter for use by children, 200 millimeters for adults. Unsupported fiberglass should not be used in construction.

Figure 8-5. Water-seal Squatting Plate for Pour-flush Toilets Located Immediately above the Pit
(millimeters)

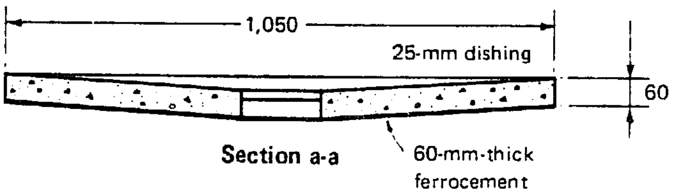


Sectional elevation

Plan of water seal



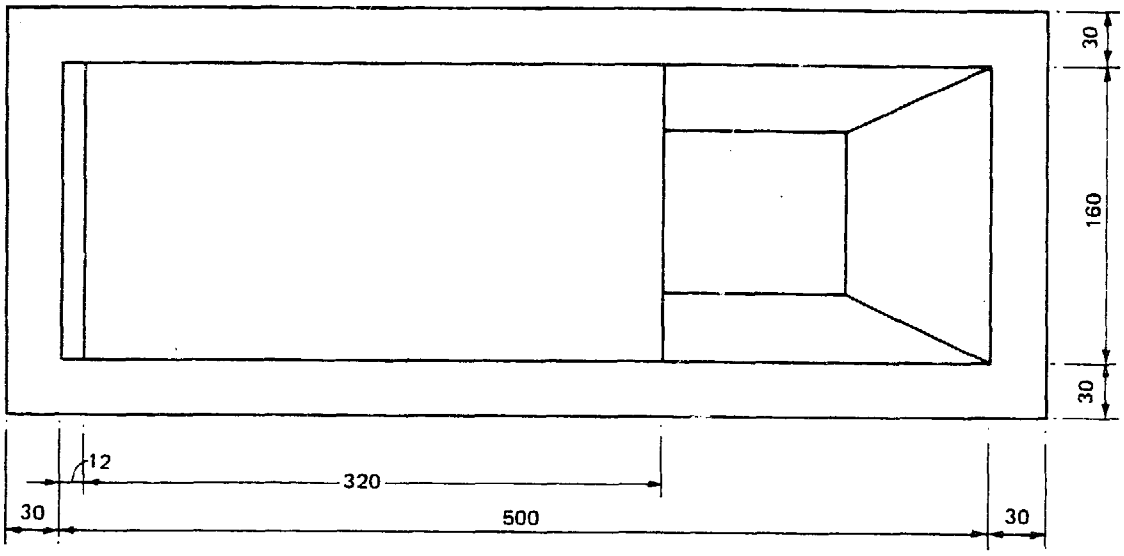
Details of squatting plate



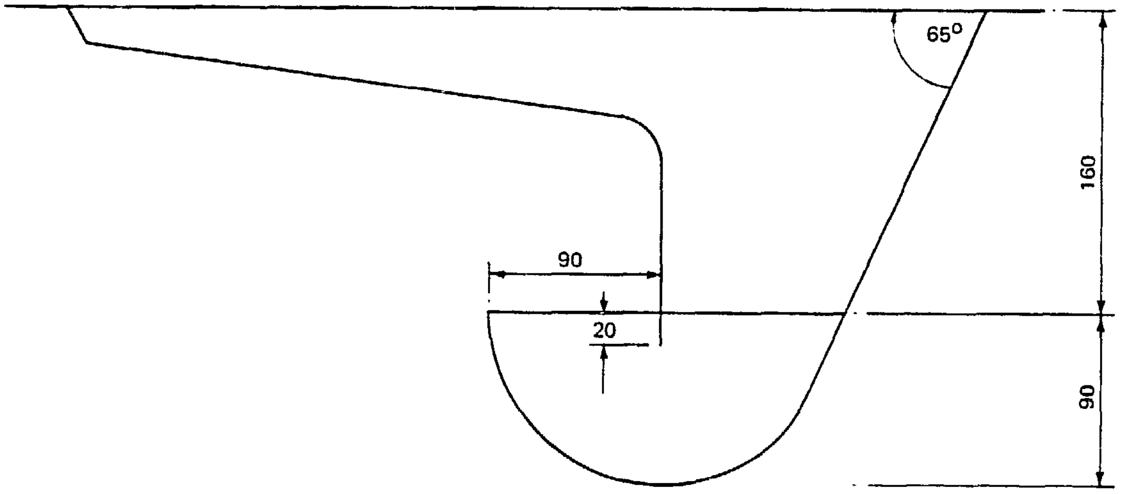
Section a-a

Source: Adapted from Wagner and Lanoix (1958).

Figure 8–6. Galvanized Sheet-metal Water-seal Unit for Pour-flush Toilets Located Immediately above the Pit (millimeters)

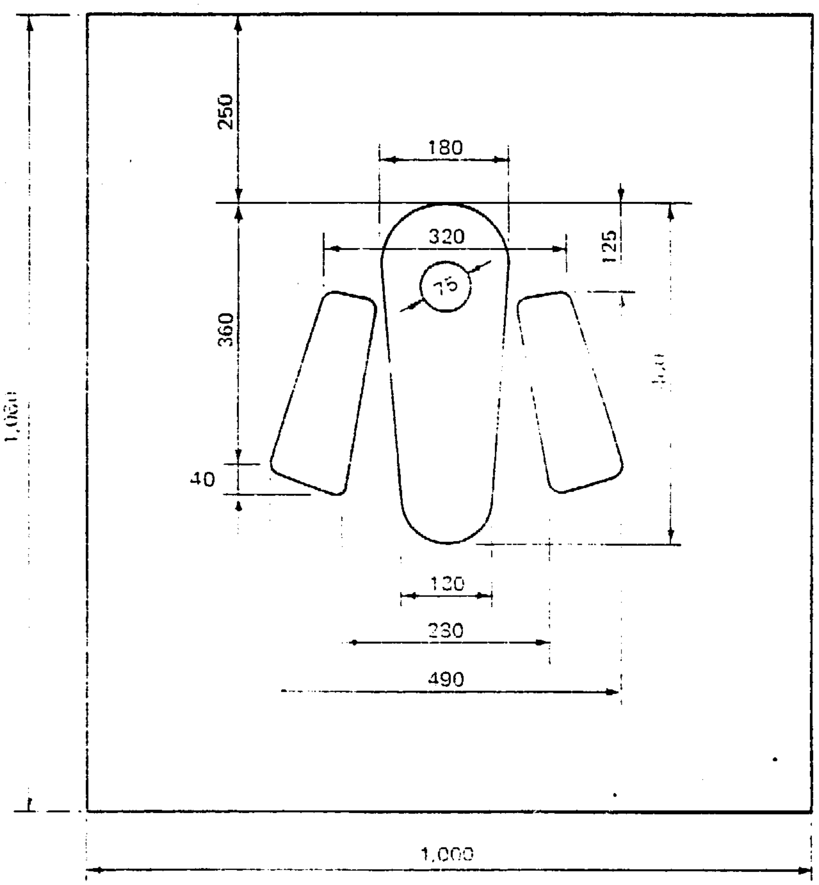


Plan

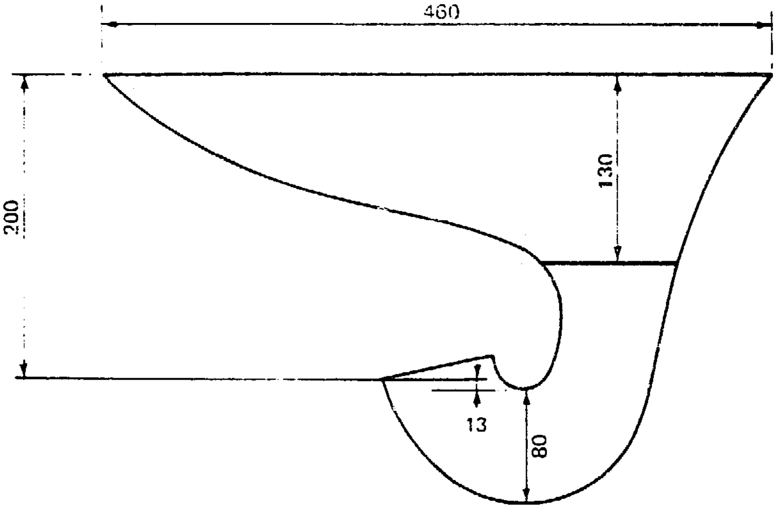


Section

Figure 8-7. Plastic or Fiberglass Water-seal Toilet (millimeters)



Plan

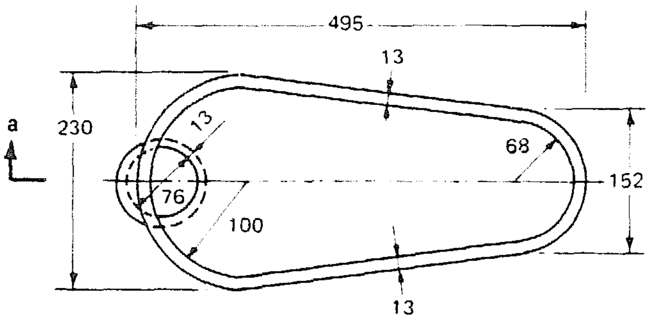


Water-seal bowl

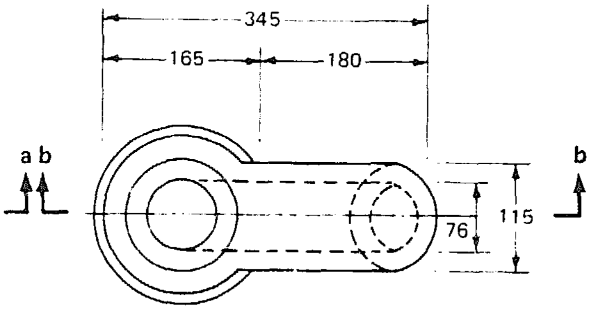
Source: Adapted from Wagner and Lanoix (1958).

Figure 8-8. Pour-flush Units for Displaced Pits (millimeters)

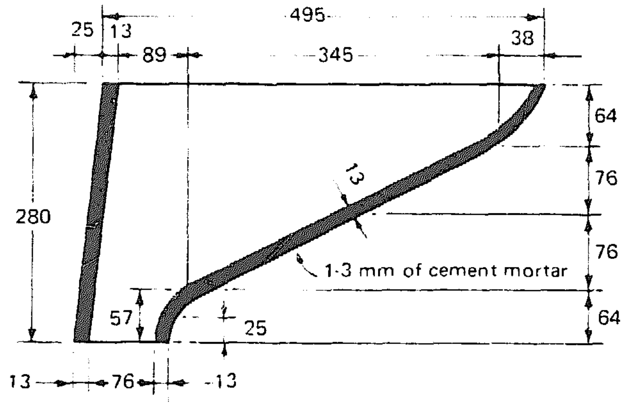
A. Cement mortar or ceramic pan



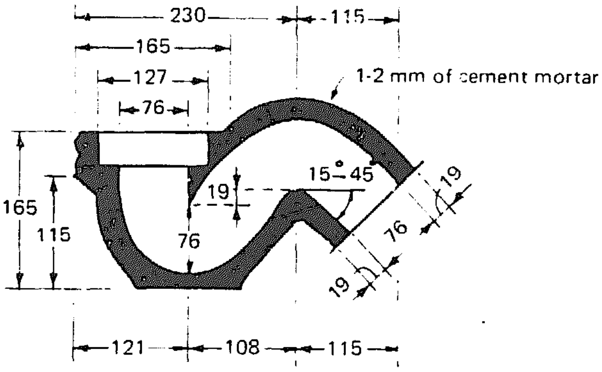
Plan of squatting plate (pan)



Plan of water-seal unit (trap)

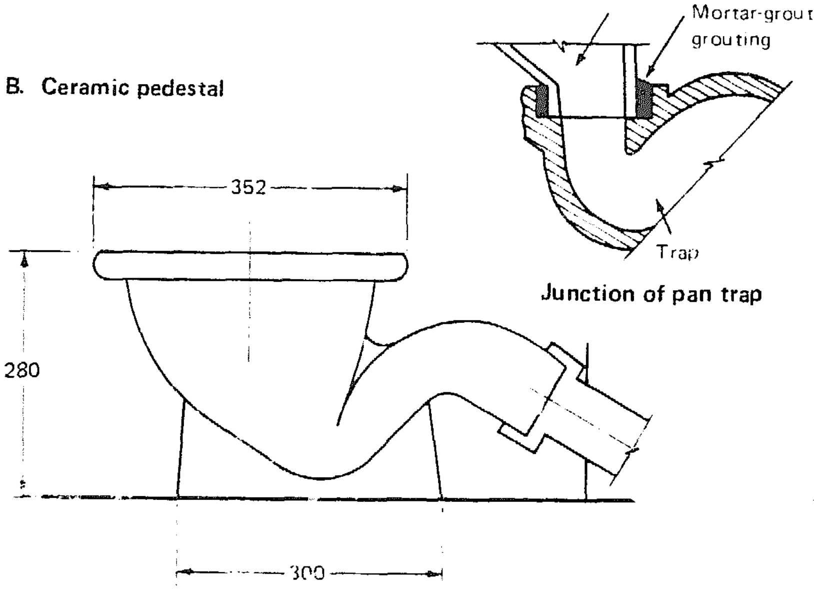


Section a-a



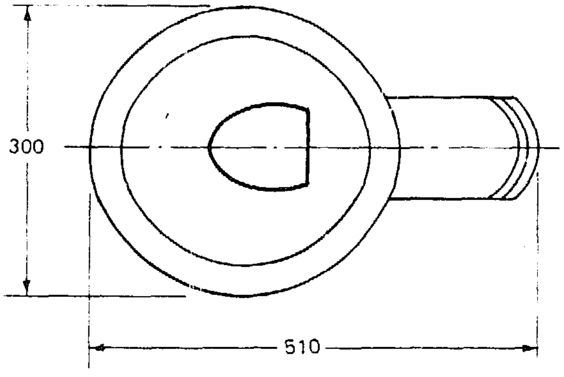
Section b-b

B. Ceramic pedestal



Junction of pan trap

Side view



Top view

Source: A, adapted from Wagner and Lanoix (1958).
B, adapted from CIMDER Colombia.

8.3 Ventilated Improved Pit (VIP) Latrines

Conventional pit latrines are the most common sanitation facility used in developing countries. In its simplest form, a pit latrine has three components--namely, a pit, a squatting plate (or seat and riser) and foundation, and a superstructure. A typical arrangement is shown in Figure 8-9. The pit is simply a hole in the ground into which excreta fall. When the pit is filled to within 1 meter of the surface, the superstructure and squatting plate are removed and the pit filled up with soil. A new pit is then dug nearby.

The simple unimproved pit latrine has two major disadvantages: it usually smells, and flies or mosquitoes readily breed in it, particularly when it is filled to within 1 meter of the surface. These undesirable attributes have led to the rejection of the pit latrine, but they are almost completely absent in ventilated improved pit (VIP) latrines, ventilated improved double-pit (VIDP) latrines, and Reed Odorless Earth Closets (ROECs). It is therefore recommended that unimproved pit latrines of the type shown in Figure 8-9 no longer be built, and that those that do exist should be converted.

VIP Latrines

VIP latrines (Figure 8-10) are a hygienic, low-cost, and indeed sophisticated form of sanitation, have minimal fly and mosquito nuisance, and have only minimal requirements for user care and municipal involvement. The pit is slightly offset to make room for an external vent pipe. The vent pipe should be at least 75 millimeters in diameter (ranging up to 200 millimeters); it should be painted black and located on the sunny side of the latrine superstructure. The air inside the vent pipe will thus heat up and create an updraft with a corresponding downdraft through the squatting plate. Thus any odors emanating from the pit contents are expelled via the vent pipe, leaving the superstructure odor free. The pit may be provided with removable cover sections to allow desludging.

Recent work has indicated that pit ventilation may also have an important role in reducing fly and mosquito breeding. The draft discourages adult flies and mosquitoes from entering and laying eggs. Nevertheless, some eggs will be laid and eventually adults will emerge. If the vent pipe is large enough to let light into the pit, and if the superstructure is sufficiently dark, the adults will try to escape up the vent pipe. The vent pipe, however, is covered by a gauze screen so that the flies are prevented from escaping and they eventually fall back to die in the pit.

Both the vent pipe and the gauze screen must be made from corrosion-resistant materials (e.g, asbestos cement, fiberglass, PVC). Little detailed work has been done on the design of the vent pipe; at present it is recommended that the pipe diameter should be 75 to 200 millimeters and that it should extend 300 millimeters above the roof; this should be increased to 600 millimeters if the pipe cannot be located on the sunny side of the superstructure. Local wind patterns and the diurnal variation in ambient temperatures affect ventilation efficiency; theoretical and field work on these aspects is continuing.

Ventilated Improved Double-Pit Latrine

To eliminate the need to construct very deep pits, to preclude the necessity of constructing another latrine once the pit is full, and to facilitate the emptying of the pit where space for a replacement latrine does not exist, a double-pit latrine should be used. A VIDP latrine differs in design from the VIP only by having two pits (see Figure 8-11). Two pits can be provided by constructing a separation wall in the VIP pit or by constructing two separate pits. Each pit should be designed to have an operating life of at least one year.

Operation and maintenance of the VIDP is the same as that of the VIP for pit emptying. With two pits available, one pit would be used until full and then sealed while the second pit is in use. When the latter is almost full, the first pit would be emptied and put back into use once more. By alternating, the two pits can be used indefinitely. Because of the long residence time (a minimum of one year) of the decomposing excreta in the pit not in use at the time, pathogenic organisms will have been destroyed by the time the pit needs to be emptied. As a consequence, there is no danger of spreading pathogens and the excavated humus-like material can be used as a soil conditioner or disposed of without fear of contamination.

In permeable soil the liquid fraction of the excreta, together with the water used for latrine and personal cleansing, percolates into the soil and so reduces the volume of excreta in the pit. The solid fraction of the excreta is slowly decomposed by anaerobic digestion, and this also reduces the volume of excreta remaining in the pit. Thus the long-term accumulation of solids in the pit is very much less than the total quantity of excreta added. VIP latrines, VIDP latrines, and ROECs are designed for use without water, i.e., there is no need to "flush" excreta into the pit. Where flushing is desired, a pour-flush (PF) toilet should be used (see chapter 8, section 5) because it is a superior latrine for applications where water is available and the user accustomed to the use of water for flushing and/or anal cleansing.

Pits should be constructed so as not to extend below the water table so the pit remains dry and groundwater contamination is minimized. In areas where the water table is within 1 meter of the ground surface, or where excavation is extremely difficult (as, for example, in rocky ground), a built-up pit can be used, as shown in Figure 8-13. The raised plinth should not be more than 1 meter above ground level and the watertight lining should extend at least 0.5 meter, and preferably 1 meter, below ground level. With a movable superstructure, a long, shallow multiple-chamber pit can be constructed and desludged periodically.

ROECs

An alternative design for a VIP latrine is the ROEC, shown in Figure 8-12. In this latrine the pit is completely offset and excreta are introduced into the pit via a chute. A vent pipe is provided, as in the VIP latrine, to minimize fly and odor nuisance. A disadvantage of the ROEC, however, is that the chute is easily fouled with excreta and thus may provide a site for fly breeding; the chute therefore has to be cleaned regularly with a long-handled brush. In spite of this small disadvantage, ROECs are sometimes preferred to VIP latrines for the following reasons:

(1) the pit is larger and thus has a longer life than other shallow pits;

(2) since the pit is completely displaced, the users (particularly children) have no fear of falling into it;

(3) it is not possible to see the excreta in the pit; and

(4) the pit can easily be emptied, so that the superstructure can be a permanent facility.

Pit Design

The volume (V) of pits less than 4 meters deep may be calculated from the equation:

$$V = 1.33\ CPN;$$

where C = pit design capacity, cubic meter/person per year;

P = number of people using the latrine;

N = number of years the pit is to be used before emptying.

The capacity (C) of dry pit should be 0.6 cubic meter per person per year. Where anal cleansing materials that are not readily decomposed (such as grass, leaves, maize, mud balls, cement bags, etc.) are used, this figure should be increased by 50 percent. For wet pits, the capacity should be 0.04 cubic meter per person per year.

The factor 1.33 is introduced as the pit is filled in with earth or emptied when it is three-quarters full. For the unusual case of pits deeper than 4 meters, $V = CPN+1$ to allow for filling the upper 1 meter with earth. Where soil conditions permit, large diameter or cross-section pits may be constructed, although special care must be given to supporting the latrine base and superstructure. Some traditional pit designs are shown on Figure 8-13.

VIP and VIDP Latrines. In the case of VIP latrines the pit is around 1 square meter in cross-section and its depth is then readily calculated from the required volume. Depths are usually in the range from 3 to 8 meters although pit depths of 12 meters or more are found where soils are particularly suitable. With VIP latrines, it may be advantageous to use enlarged pits provided the ground conditions are suitable.

The upper part of the pit should be lined so that it can properly support the squatting plate and superstructure. If this is not done, the pit may collapse. In unstable soil conditions it may be necessary to extend this lining down to the bottom of the pit (Figure 8-13), but care must be taken to ensure that the lining does not prevent percolation.

A VIDP latrine differs from a VIP only in that it has two alternating pits. When one is full, the pit should rest at least one year before it is emptied to ensure pathogen destruction--pit depths can be varied to reflect soil condition (i.e., ease of construction) and desired emptying frequency. To facilitate emptying and prevent collapse of the partition wall, however, the pit should not be as deep as that of a VIP.

All pits should be constructed to prevent surface water from entering. This requires grading to ensure diversion of surface drainage. In cases where the pit is partially offset from the superstructure, it should normally be constructed on the downhill side.

ROECs. These latrines normally have the advantage over VIP latrines that the pit, being completely offset, can be larger and thus lasts longer. The design lifetime should be 15 to 20 years. The width of the pit is generally about 1 meter and, for easy desludging, its depth should not exceed 3 meters; its length can thus be readily calculated from the equation given above (see Figure 8-12).

Borehole latrines. This type of pit latrine is not recommended as a household sanitation facility since it is too small (usually only 400 millimeters in diameter and up to 4 meters deep for hand augers) and cannot be ventilated. Borehole latrines thus have a short lifetime (1 to 2 years) and generally unacceptable levels of fly and odor nuisance. Where mechanical augers are available, greater depths and lifetimes can be provided but ventilation is still a problem (see Figure 8-13).

Material and Labor Requirements

Unskilled labor is required for excavation of the pit, and semiskilled labor is required for lining the pit, casting the squatting plate, and building the superstructure. Usually the unskilled labor can be provided by the householder, with municipal guidance and inspection.

Complementary Investments

Sullage disposal facilities are required. The precise type of facility depends on the quantity of sullage generated by the household (see chapter 9, section 1, and chapter 10).

Water Requirements

Only minimal volumes of water are required to clean the squatting slab and, if customary, for anal cleansing (though in the latter case a PF unit would be better).

Maintenance Requirements

Pit latrines require good maintenance. This maintenance, however, is of a very simple kind and consists principally of keeping the squatting plate and superstructure clean. To prevent mosquito breeding in wet pits, a cupful of a suitable inhibitor (such as wood ash, lye, used lubricating oil, kerosene, or boron) should be added to the pit each week.

Factors Affecting Suitability

VIP and VIDP latrines and ROECs are suitable in low- and medium-density areas (up to approximately 300 people per hectare). In such areas houses are normally single-storied and there is sufficient space on each plot for at least two pit sites (one in use and the other in reserve). They can be used at much higher densities (500 to 600 people per hectare), however, if the pit volume is increased or if pits and vaults are easily accessible for emptying and if sullage water disposal is properly managed. The VIDP is particularly useful at high densities. All three types of latrine are easy to construct (except in sandy or rocky ground, or when the water table is high), and usually much, if not at all, of the construction can be done by the users. The construction materials are standard and none generally has to be specially imported.

Health Aspects

Provided the squatting plate is kept clean, a VIP latrine or ROEC poses a health risk to the user scarcely greater than does a flush toilet. The only slightly increased risk is that of fly and mosquito breeding. This is most unlikely to be a serious nuisance, however, if the latrine is kept clean, fly-breeding inhibitors are used, the ventilation system is properly designed, and the users keep the slab hole covered.

Costs

The total construction cost of a VIP or VIDP latrine ranges from $50 to $150; the lower figure assumes household labor is used for excavation and building the superstructure. If the ground is rocky or no inexpensive superstructure materials are available the cost may be higher than $150. With a larger pit than that of the VIP latrine and the addition of a chute, an ROEC will cost about $75 to $200 to construct. The operating and maintenance requirements of VIP or VIDP latrines and ROECs are those of cleaning the user area and periodic emptying.

Potential for Upgrading

VIP latrines, VIDP latrines, and ROECs can be easily upgraded to PF toilets. The necessary design modifications are discussed in chapters 6 and 7.

Potential for Resource Recovery

VIDP latrines permit waste reuse; when dug out, the well-aged pit contents may be safely used as humus on gardens. The contents of VIP and ROEC pits will, however, contain some fresh excreta and will require treatment (if by composting) before they can be safely used.

Main Advantages and Disadvantages

The main advantages of well-maintained VIP latrines, VIDP latrines, and ROECs are:

(1) lowest annual costs;

(2) ease of construction and maintenance;

(3) all types of anal cleansing materials may be used;

(4) absence of odor nuisance and minimal fly and mosquito nuisance;

(5) minimal water requirements;

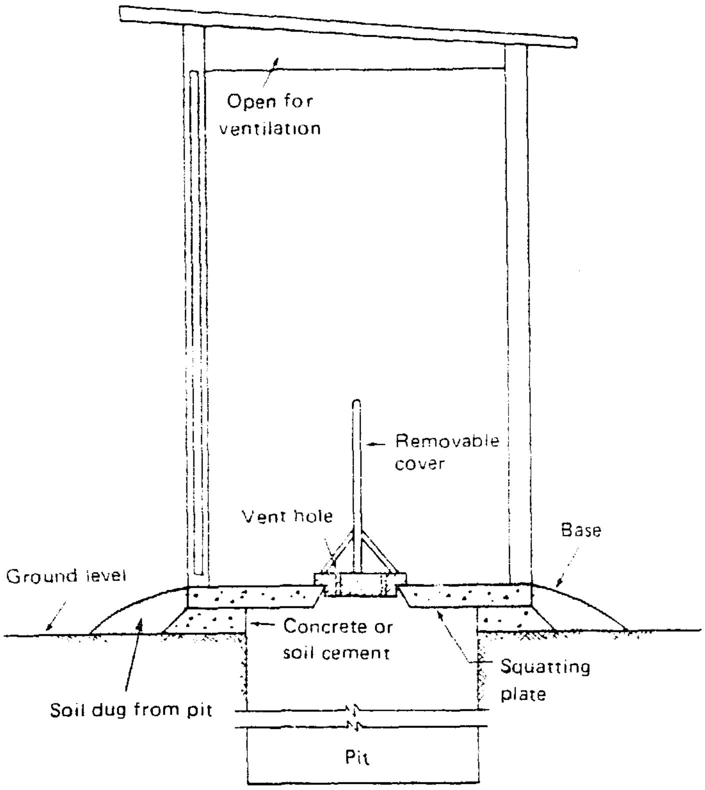
(6) low level of municipal involvement;

(7) minimal risks to health; and

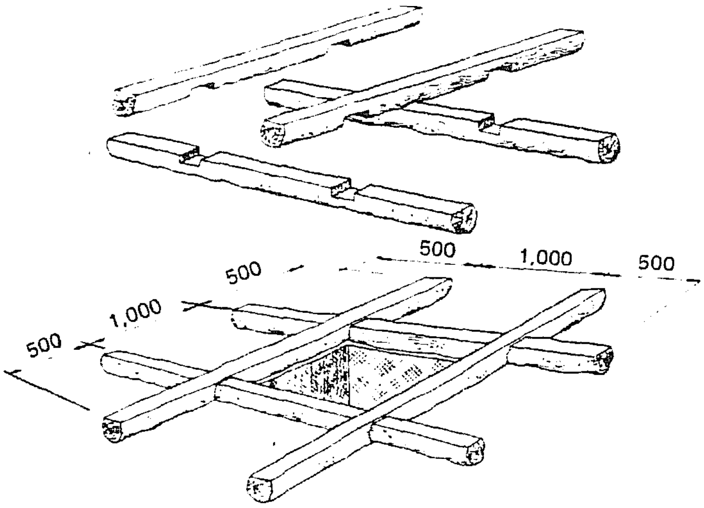
(8) good potential for upgrading.

Their main disadvantages are that they are unsuitable for high-density urban areas, they may pollute the groundwater, and that, when full, they must be taken out of service and another unit built (except in the case of VIDP). They can be upgraded to PF toilets if users desire the advantages of a water flushed unit with a water seal. They also require that separate arrangements be made for sullage disposal.

Figure 8--9. Conventional Unimproved Pit Latrines (millimeters)



Side view

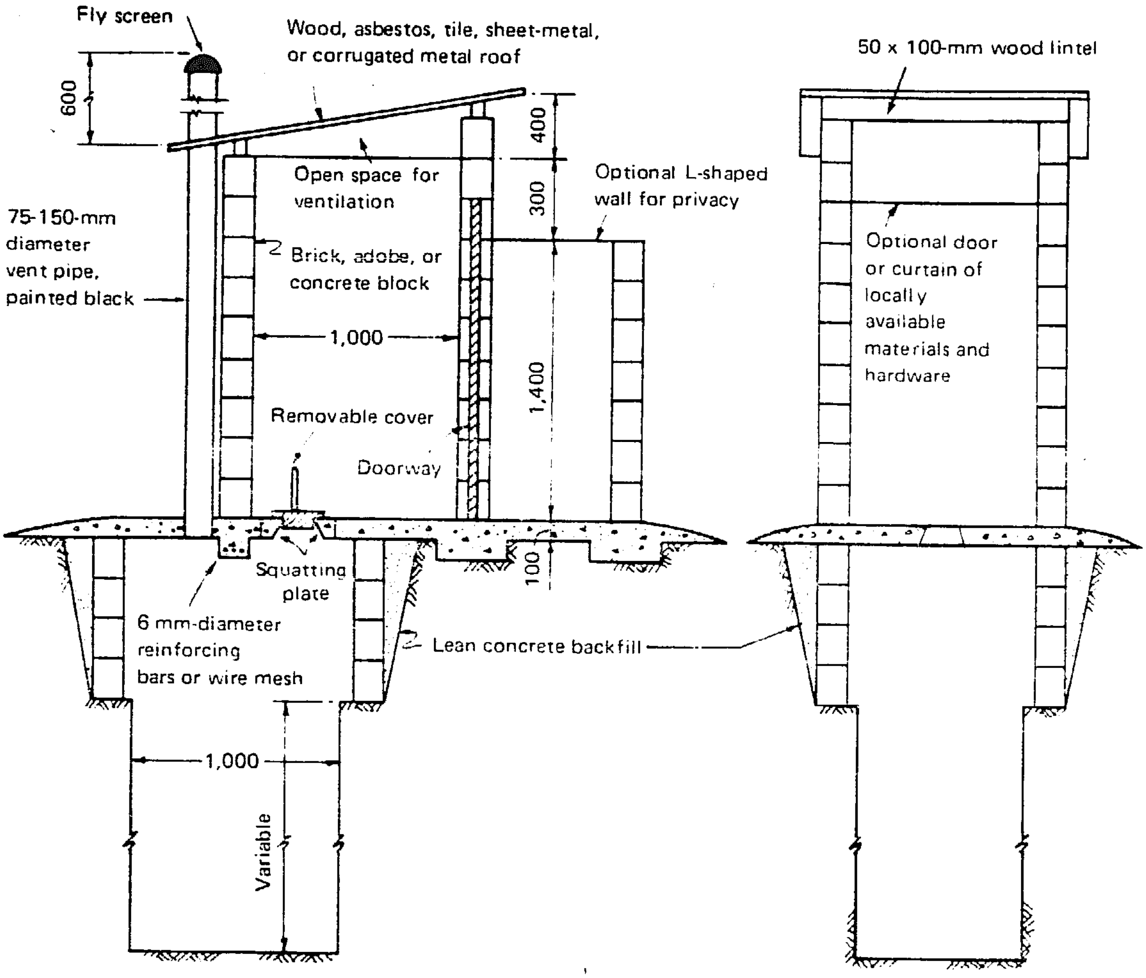


Alternative base using hewn logs

Note: In termite-infested areas, use treated wood or termite barrier.

Source: Adapted from Wagner and Lanoix (1958).

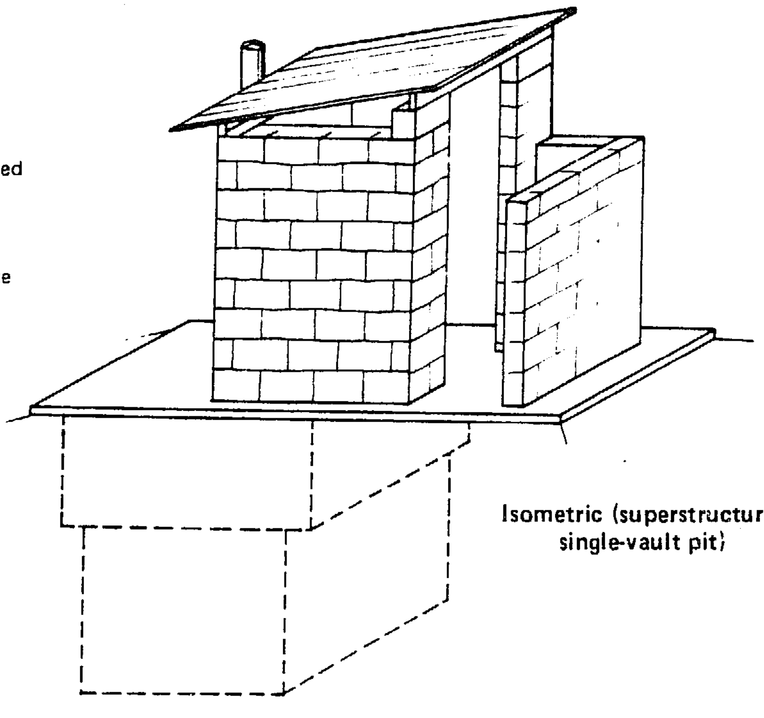
Figure 8-10 . Ventilated Improved Pit Latrine (measurements in millimeters) (millimeters)



Side view (section)

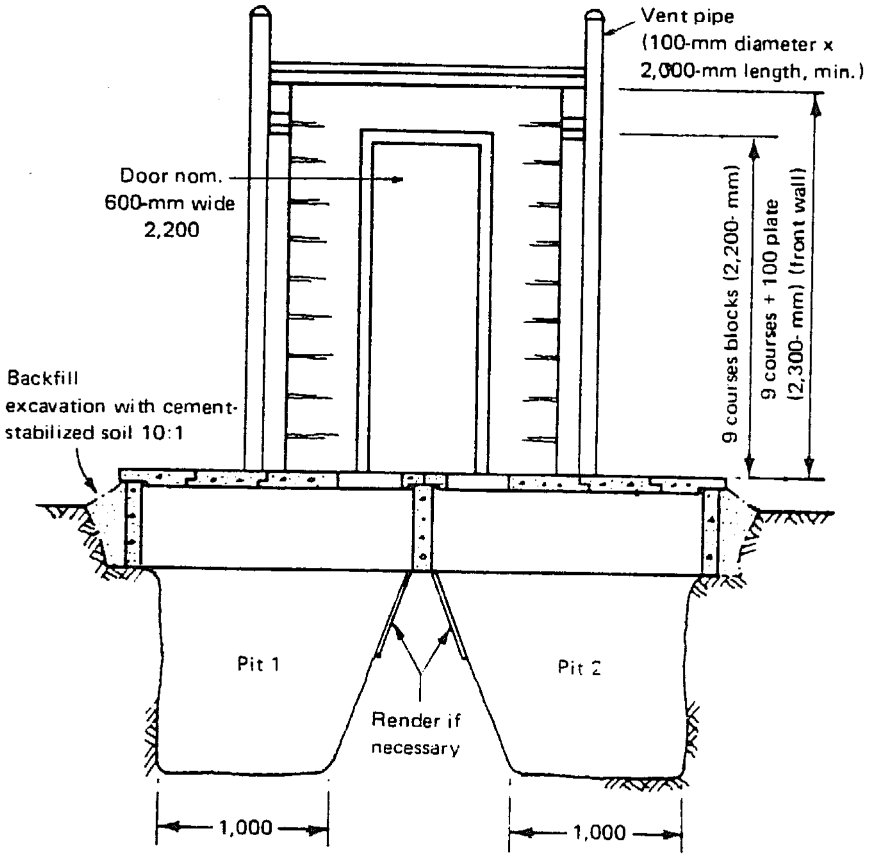
Front view (superstructure; L-shaped wall and vent not shown)

Note: Side view. Pedestal seat or bench may be substituted for squatting plate. An opening for desludging may be provided next to vent. Dimensions of the bricks or concrete blocks may vary according to local practice. Wooden beams, flooring, and siding may be substituted for concrete block walls and substructure.

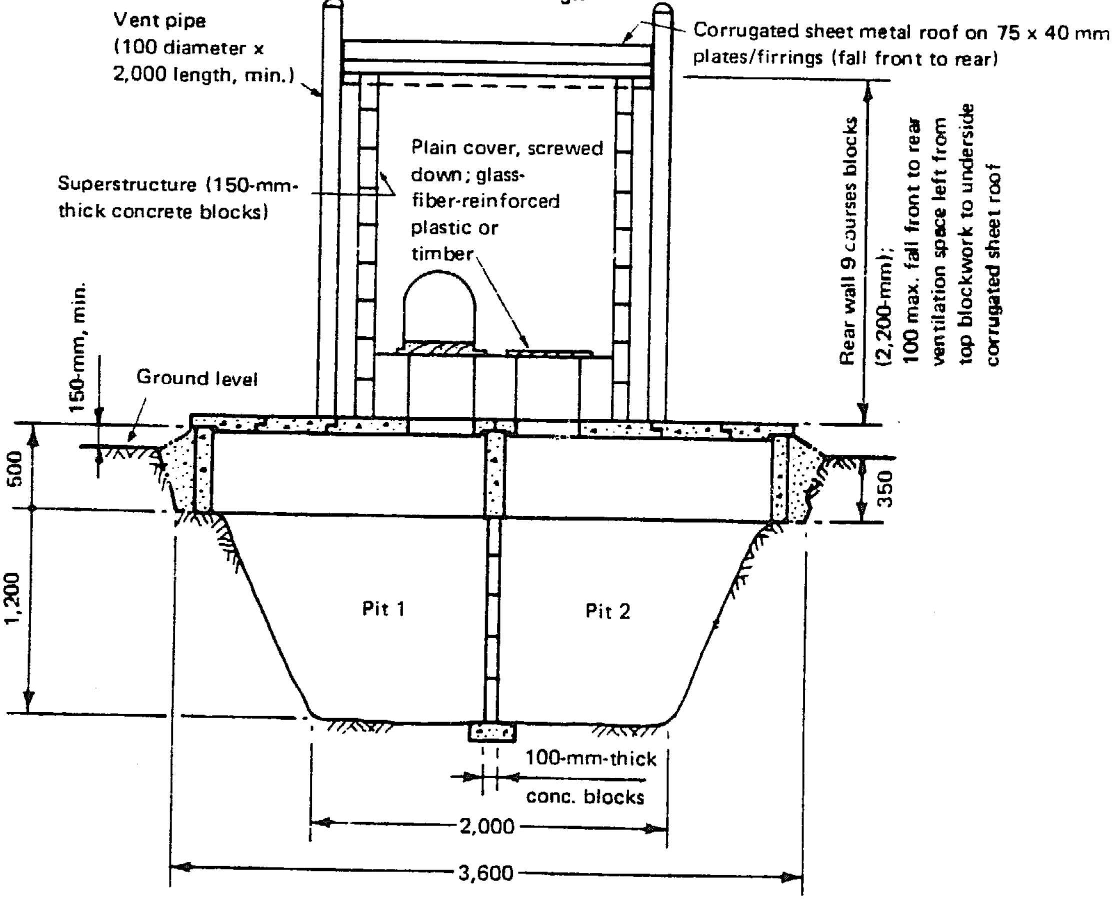


Isometric (superstructure; single-vault pit)

Figure 8-11 . Ventilated Improved Double-pit Latrine (millimeters)



Standard design

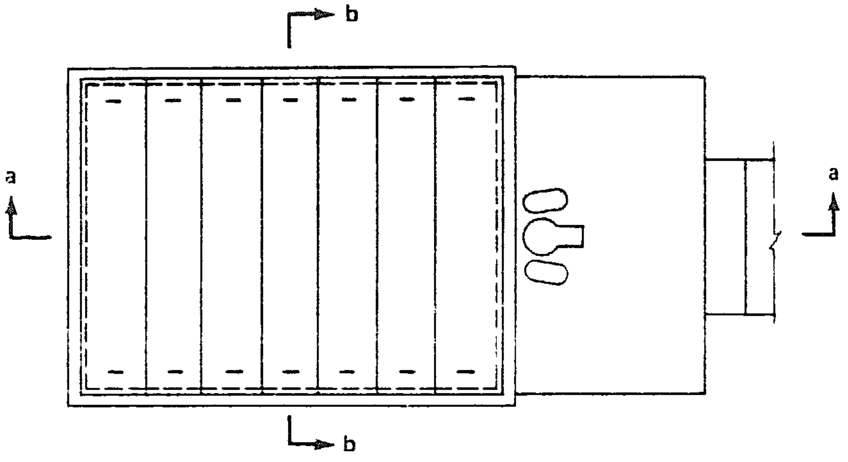


Optional design

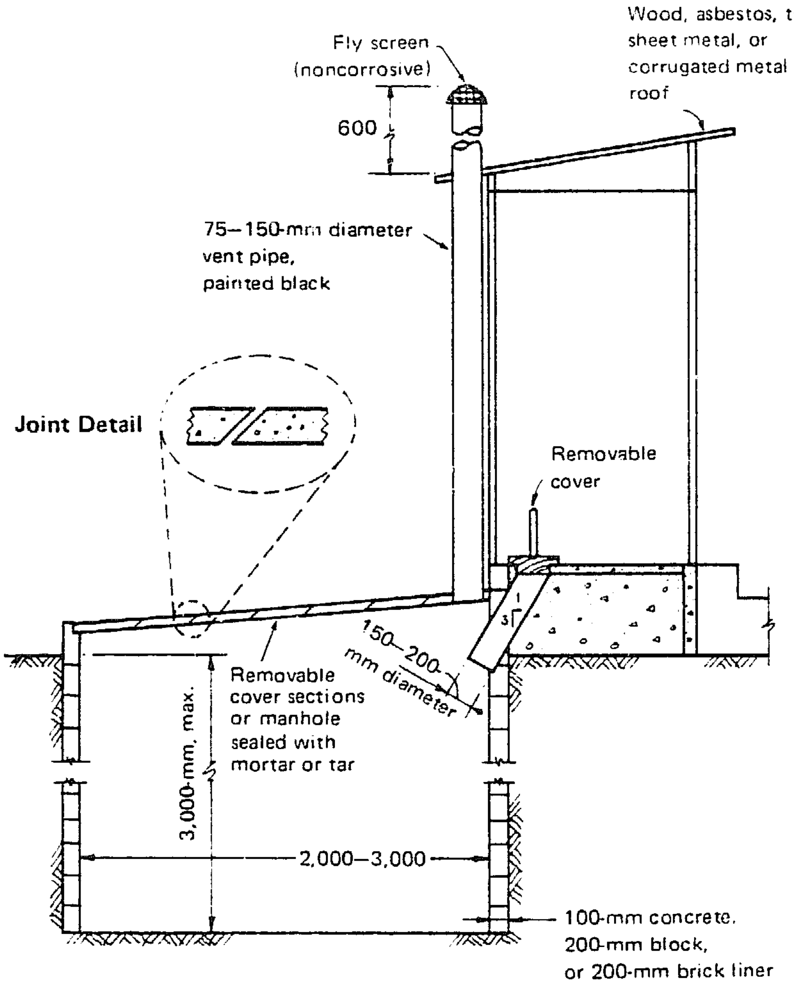
Source: Adapted from R. Carroll (1979).

Figure 8-12. Reed Odorless Earth Closet (ROEC)
(millimeters)

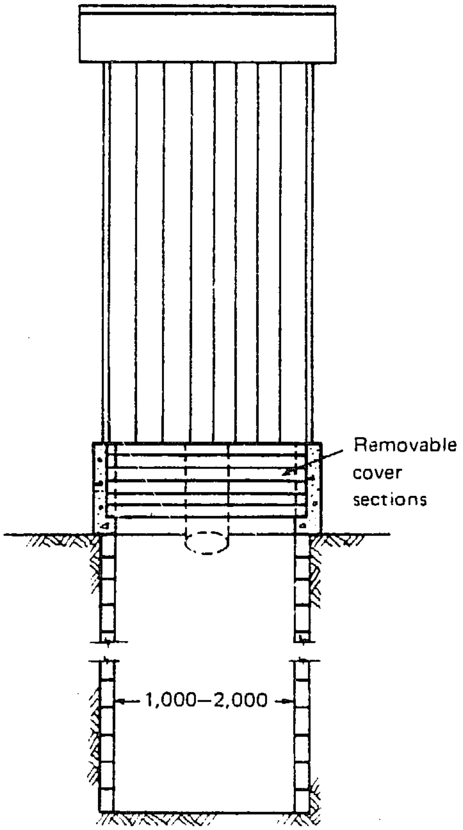
A. Plan



Plan (with latrine superstructure removed)

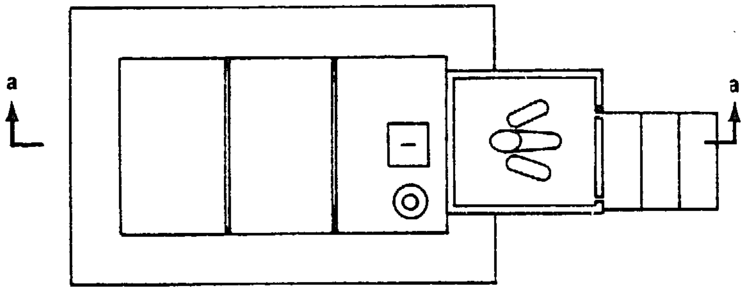


Section a-a

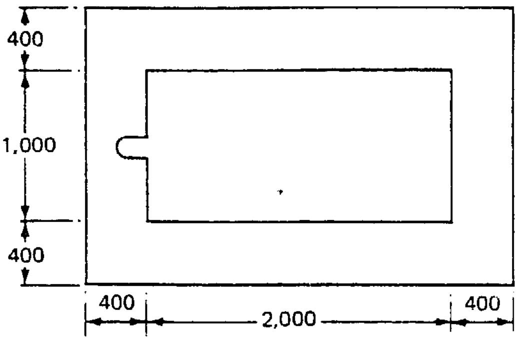


Section b-b
(vent not shown)

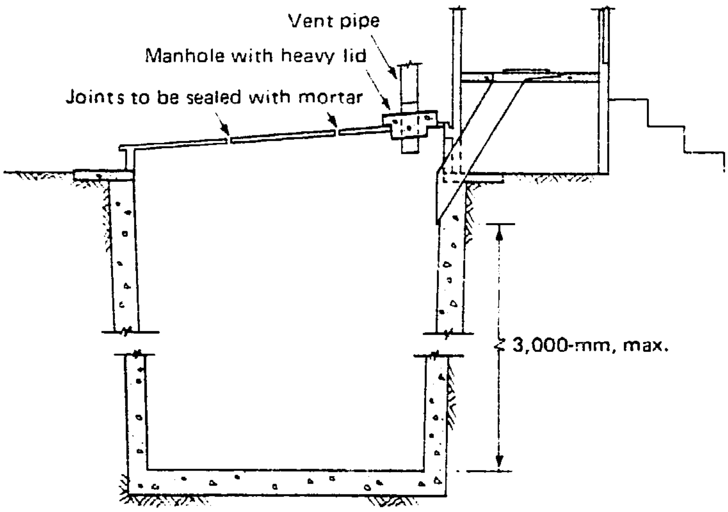
Figure 8-12 . (continued)
B. Structural details



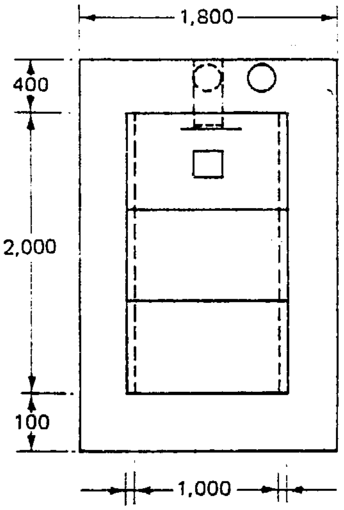
Plan



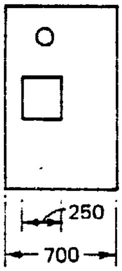
Plan of pit collar



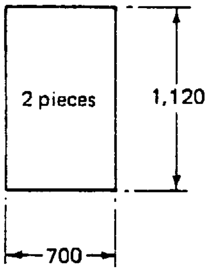
Section a-a



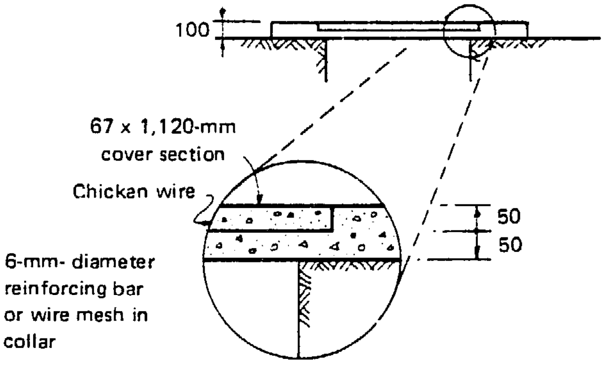
Alternative concrete collar and cover sections for 1,000 x 2,000-mm unlined pit



Fixed lid



Removable lid

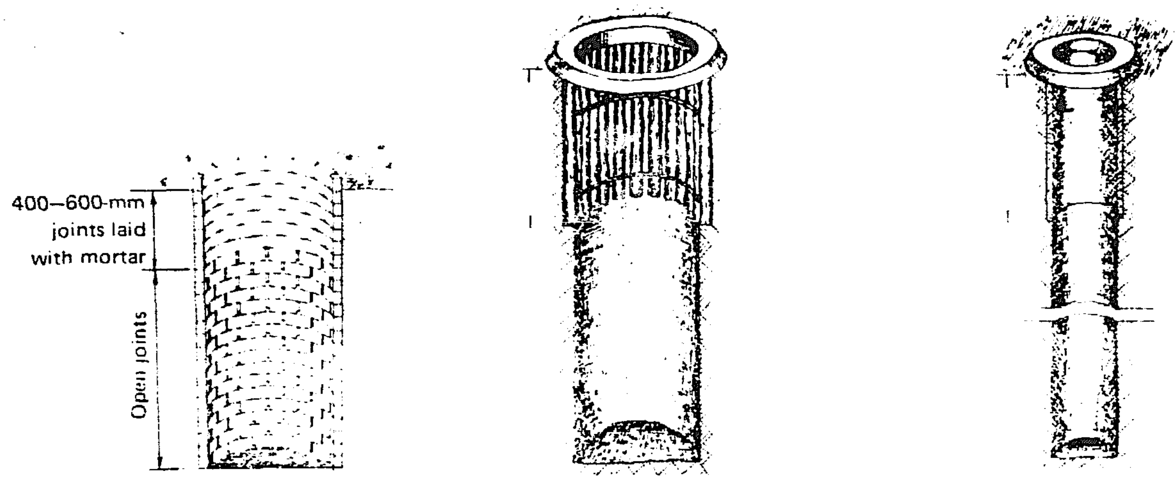


Detail of cover section

Note: Pedestal seat with curved chute may be substituted for squatting plate. Construction materials and dimensions for superstructure may vary according to local practice. The vent should be placed for maximum exposure to sunlight.

Source: Adapted from Wagner and Lanoix (1958).

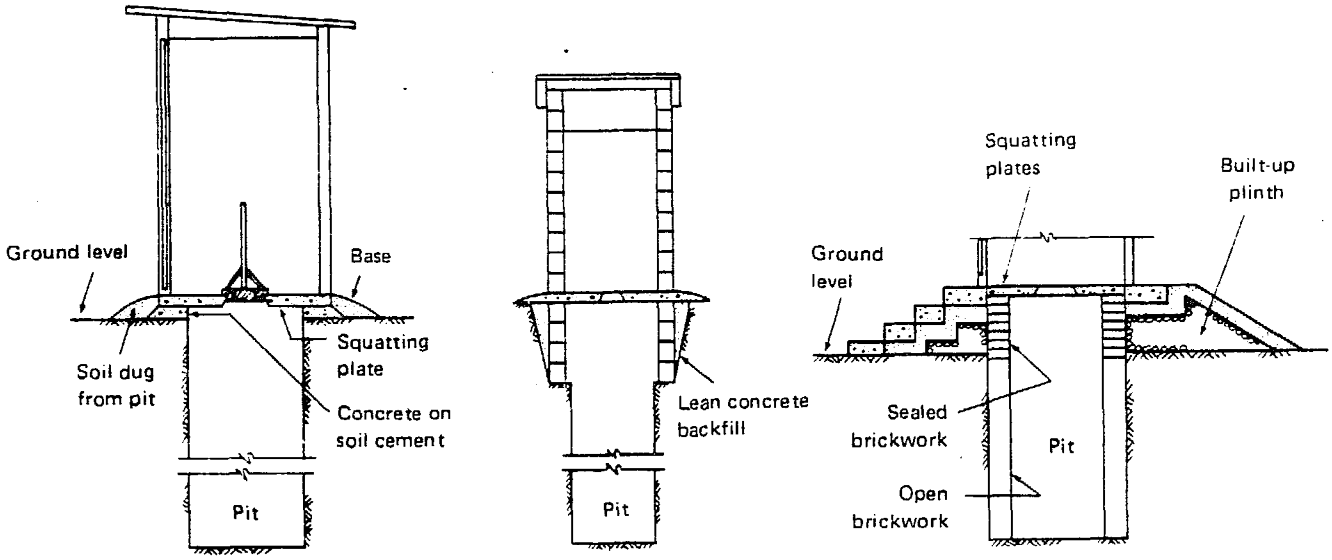
Figure 8- 13 . Alternative Pit Designs (millimeters)



Circular pit with brick lining

Round pit with partial lining of tree limbs

Bored pit with concrete lining



Unlined pit

Square pit with partial concrete-block lining

Raised pit latrine for use in areas of high groundwater table

Source: Top, adapted from Wagner and Lanoix (1958); bottom, World Bank.

8.4 Composting Toilets

Household systems for composting night soil and other organic materials are used under a variety of conditions. They are successful in both developing and industrial countries when they receive a high degree of user care and attention. This is most likely to occur when there is an urgent need for fertilizer or when there is a high degree of environmental concern. There are two types of systems, continuous and batch.

Continuous Composting Toilets

Continuous composting toilets are developments of a Swedish design known as a "multrum" (see Figure 8-14). They are extremely sensitive to the degree of user care: the humus has to be removed at the correct rate, organic matter has to be added in the correct quantities, and only a minimum of liquid can be added. Even with the required sophisticated level of user care, short circuiting may still occur within the system, and viable excreted pathogens can be washed down into the humus chamber. The results of these field trials indicate that continuous composting toilets are presently not suitable for use in developing countries.

Batch Composting Toilets

Double vault composting (DVC) toilets are the most common type of batch composting toilet. Designs are shown in Figures 8-15 and 8-16. The design details, such as fixed or movable superstructures, vary, but all DVC toilets have certain design principles and operational requirements in common. There are two adjacent vaults, one of which is used until it is about three-quarters full, when it is filled with earth and sealed, and the other vault is then used. Ash and biodegradable organic matter are added to the vault to absorb odors and moisture. If ash or organic matter is not added, the toilet acts either as a VIP latrine, if it is unsealed, or as a vault toilet, if it is sealed. When the second vault is filled and sealed, the contents of the first vault are removed and it is put into service again. The composting process takes place anaerobically and requires approximately one year to make the compost microbiologically safe for use as a soil fertilizer.

To produce good composted humus, the optimum moisture content in the vault should be between 40 and 60 percent. This can be achieved in several ways. In the Vietnamese DVC toilet (Figure 8-15) urine is excluded from the vault and either drained to a small gravel soakaway or collected for use as a nitogenous liquid fertilizer. This is unlikely to be acceptable in areas where the prevalence of urinary shistosomiasis is high. In the Botswanan and Tanzanian DVC toilets (see Figure 8-16) the base of the vault is permeable, permitting infiltration and percolation of urine and water; clearly this approach is not applicable in areas where there is a high groundwater table.

Material and Labor Requirements

Construction material and labor requirements are generally comparable to those for VIP latrines and ROECs, providing special care is given to making the vaults waterproof. Separate urine channels may be needed to improve nitrogen recovery, reduce supplemental carbon requirements, and reduce moisture content.

Complementary Investments

Sullage disposal facilities are required (see chapter 10).

Water Requirements

A small quantity of water is required to clean the squatting plate. Only the absolute minimum of water should be added to DVC toilets.

Maintenance Requirements

Batch composting or DVC toilets require great user care and maintenance. Ash and easily biodegradable organic wastes such as sawdust, grass, and vegetable wastes must be regularly added in the correct quantities to maintain a suitable carbon-nitrogen ratio in the composting material. Where such material is not easily available (due to changes in household customs, such as cooking with gas rather than wood, which eliminates the availability of ash), composting toilets are not recommended. Care must be taken to exclude water. Finally the vaults must be properly sealed with earth when they are three-quarters full, the other vault emptied and put into service, and its contents reused on the land.

DVC toilets are relatively easy to build on a self-help basis, and municipal authorities are generally only required to supervise their design and construction and to organize appropriate forms of credit for the smallholder. A continuing long-term and vigorous program of user education, however, will normally be necessary in order to ensure that DVC toilets are used correctly.

Factors Affecting Suitability

DVC toilets are not suitable in areas where:

(1) sufficient user care cannot be reasonably expected;

(2) there is insufficient organic waste material available;

(3) the users are unwilling to handle the composted humus; and

(4) there is no local use or market for the humus produced.

In high-density areas DVC toilets may be unsuitable because it is highly unlikely that the users will be motivated to produce good humus for agricultural use, and in any case they are unlikely to have sufficient waste material to regulate the moisture and carbon content of the vault contents.

Health Aspects

Vault ventilation reduces odor and fly nuisance, and if the squatting plate is kept clean, DVC toilets do not pose significant risks to health. Provided each vault can store excreta for 1 year, the composted humus can be safely handled and used on the land because only a few viable Ascaris ova will be present.

Costs

The total cost of DVC toilets built as part of pilot projects in Africa ranged from $150 to over $550. It is likely, however, that a typical DVC toilet with a modest superstructure could be built for $100 to $300. Operating and maintenance costs would be negligible if the household removed the compost for its own use. If the municipality collected the compost and transported it for use, the operating costs could be significant.

Potential for Upgrading

There is usually no need to upgrade DVC toilets They can, however, be converted to PF toilets if desired and if the soil is sufficiently permeable. Their conversion to sewered PF toilets is straightforward since they have two vaults, one of which can be used for excreta and the other for sullage. This conversion is especially attractive (indeed may be necessary) if the housing density increases substantially so that the land available to the householders on which they can be reuse their excreta decreases and on-site sullage disposal is no longer possible.

Potential for Resource Recovery

DVC toilets are specifically designed for resource recovery.

Main Advantages and Disadvantages

DVC toilets have the following advantages:

(1) the production of a stable, safe humus; and

(2) minimal water requirements.

They have the following disadvantages:

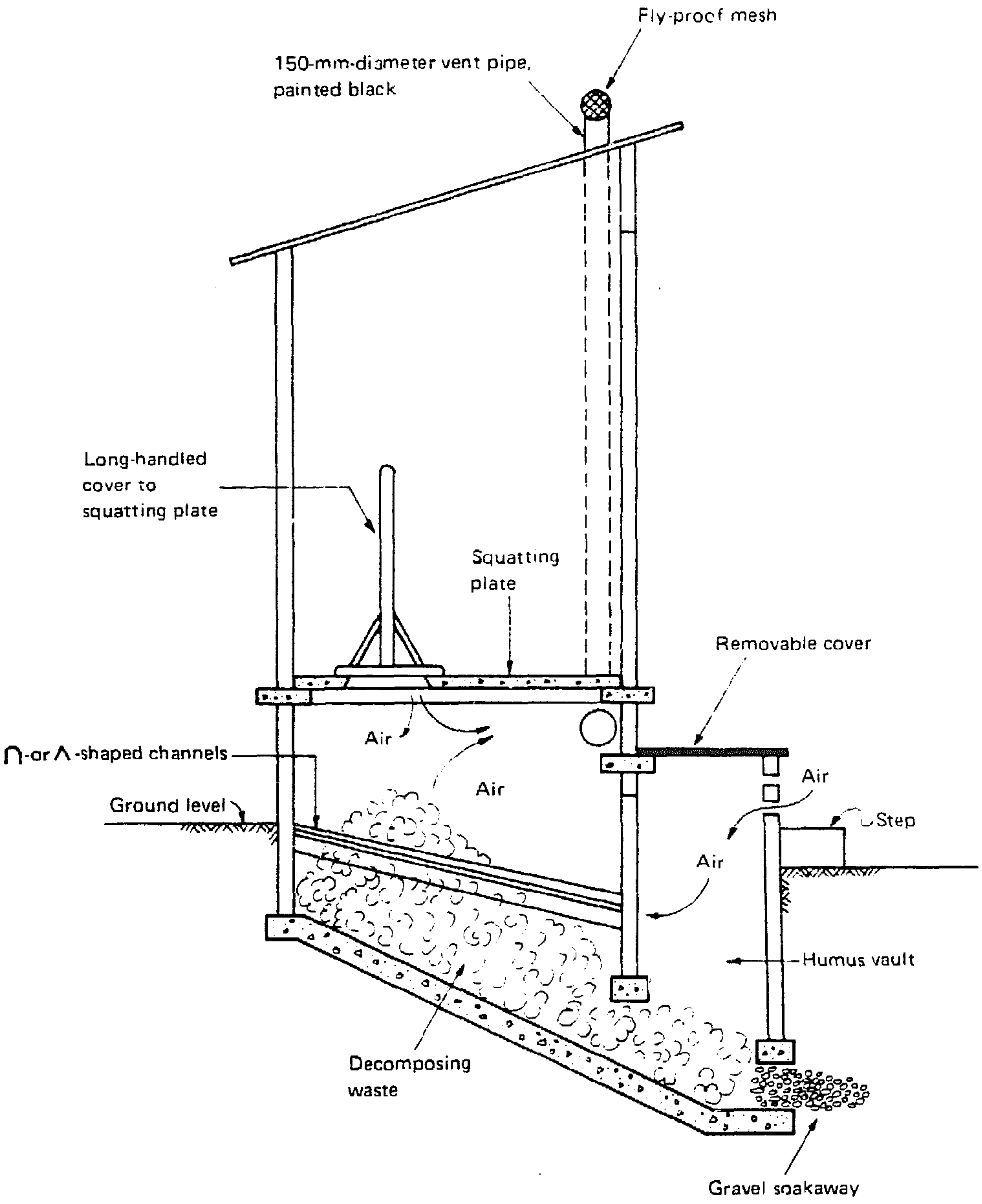
(1) an extremely high degree of user care and motivation is required for satisfactory operation;

(2) substantial quantities of biodegradable organic matter must be locally available; and

(3) they are unsuitable for high-density areas.

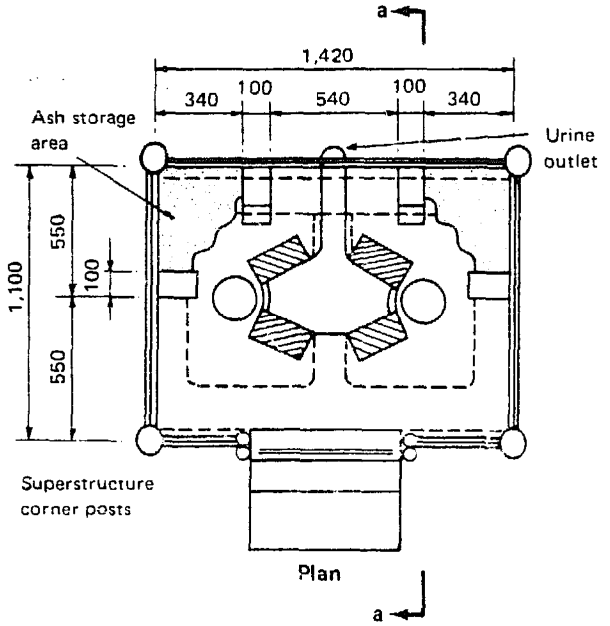
Except in societies where there is a tradition of reusing excreta in agriculture, DVC toilets have no advantages, and in fact have major disadvantages, over other forms of sanitation, and VIP latrines in particular.

Figure 8-14. "Multrum" Continuous-composting Toilet

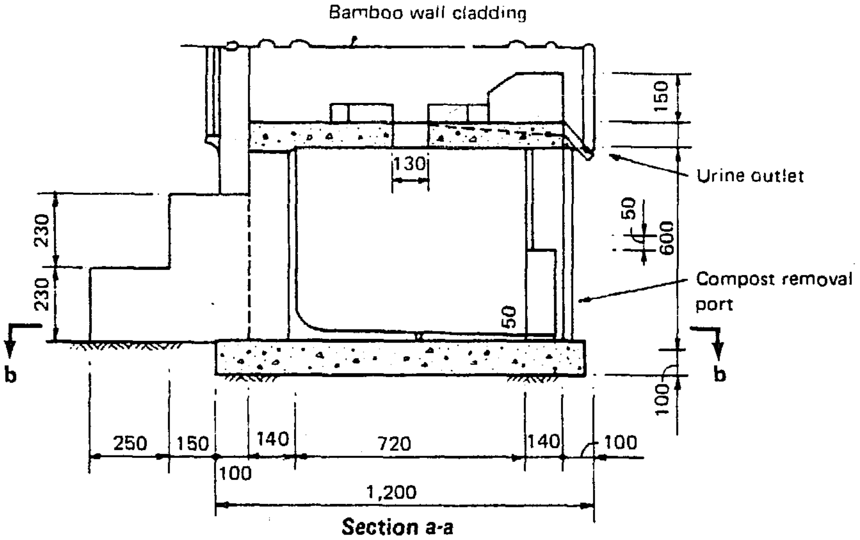


Source: Adapted from a drawing by U. Winblad.

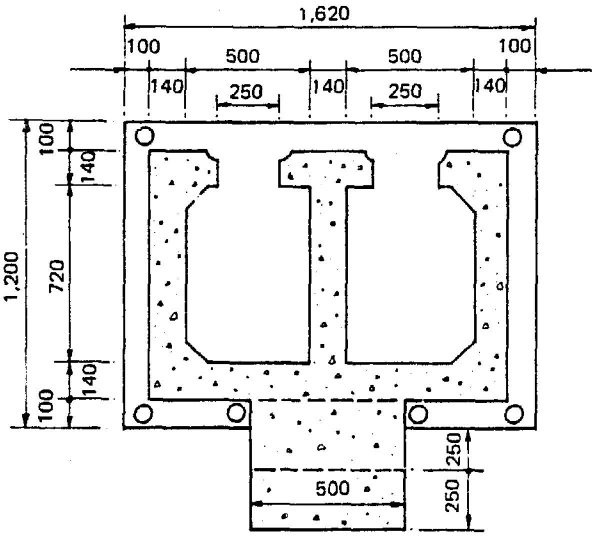
Figure 8-15 . Double-vault Composting Toilet Used in Vietnam (millimeters)



Plan

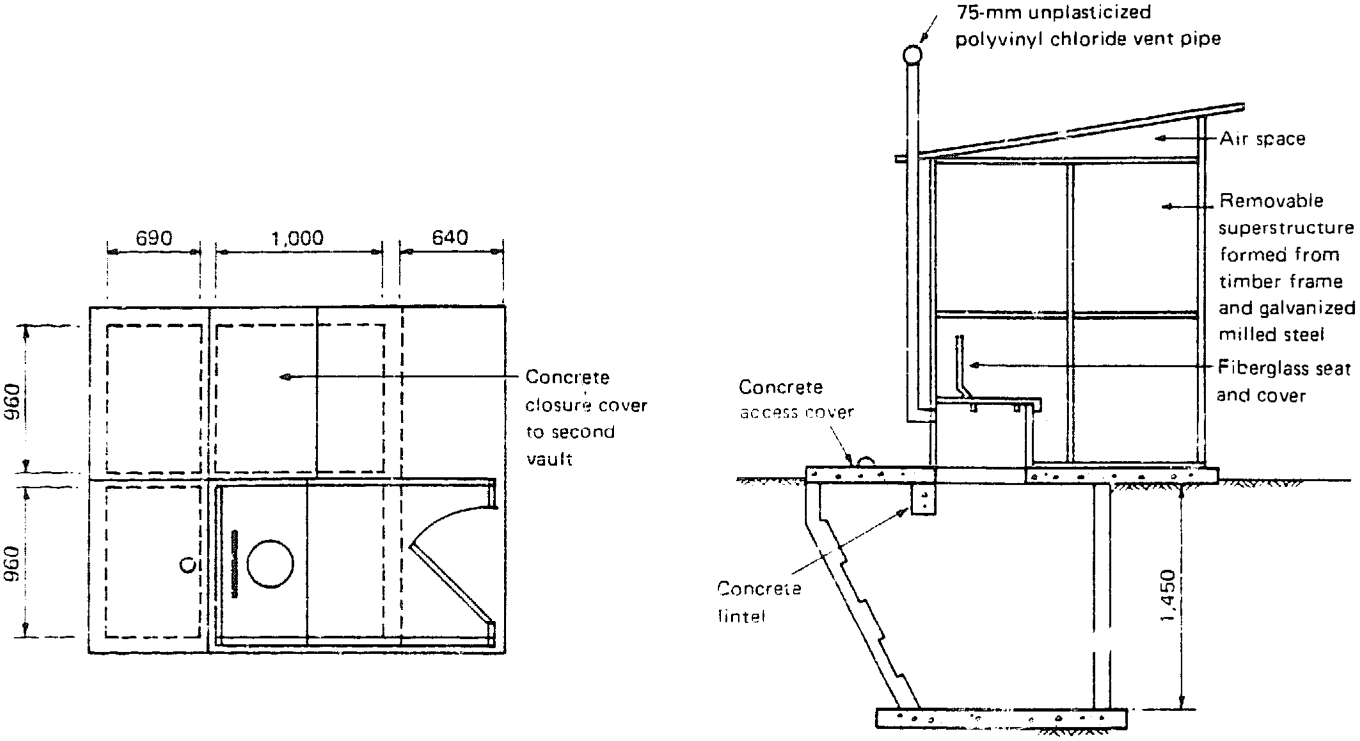


Section a-a



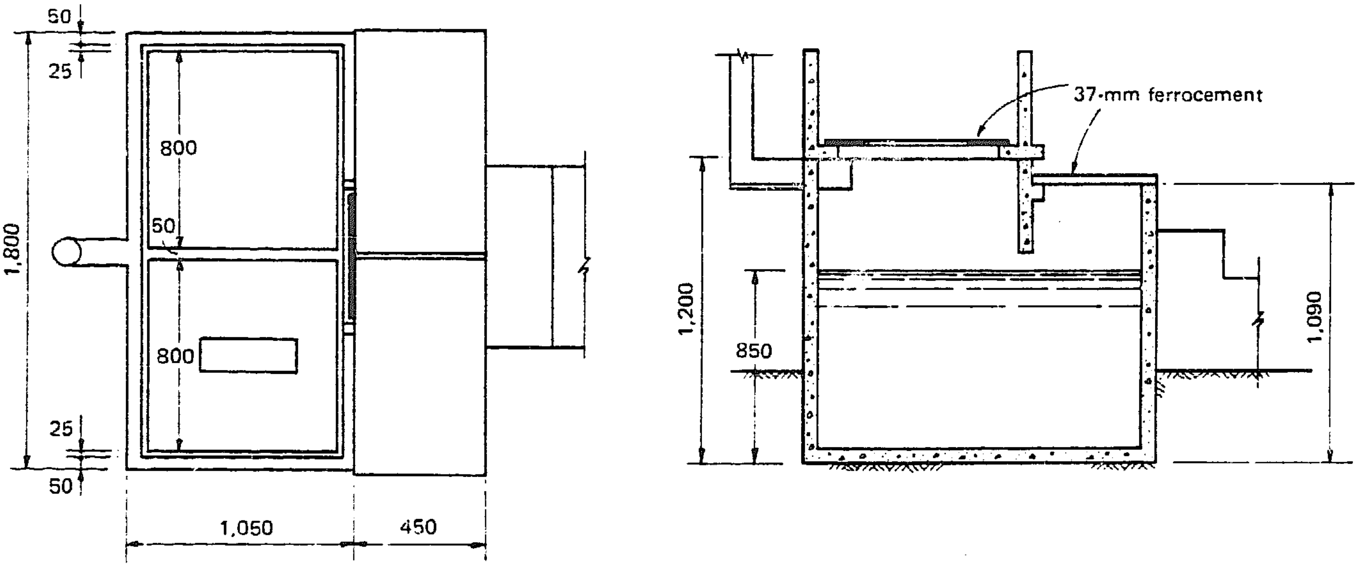
Section b-b

Figure 8-16 . Double-vault Composting Toilets (millimeters)



Plan **Section**

Model used in Botswana



Plan **Section**

Model used in Tanzania

Source: From a drawing by R.A. Boydell.

8.5 Pour-Flush Toilets

Pour-flush (PF) toilets have water seals beneath the squatting plate or pedestal seat and are available in many different designs. Two basic types are shown on Figure 8-17: the direct discharge and the offset pit design. In both design approximately 1 to 2 liters of water (or sullage) are poured in by hand to flush the excreta into the pit They can be used for several sanitation service levels. The first type is a modification of the pit latrine in which the squatting plate is provided with a simple water seal. This type is often used with wet pits since the water seal prevents odor development and mosquito breeding. It is especially suitable where water is used for anal cleansing.

The second type of PF toilet, which is widely used in India, southeast Asia, and some parts of Latin America, is used in combination with a completely offset pit. The PF bowl is connected to a short length (8 meters maximum) of 100-millimeter diameter pipe that discharges into an adjacent pit. The slope of the connecting pipe should not be less than 1 in 40.

The pit is designed as described for VIP latrines and provided with a concrete or ferrocement cover slab and wall lining as necessary. Because the digestion of excreta solids proceeds more rapidly in wet than in dry pits, however, a design capacity (C) of 0.04 cubic meter per person yearly can be used. The volume (V) of pits less than 4 meters deep may be calculated from the equation:

$$V = 1.33\ CPN,$$

where C = pit design capacity, cubic meter per person yearly P = number of people using the latrine; and N = number of years the pit is to be used before emptying.

This type of PF toilet may be installed inside the house since it is free from both odors and fly and mosquito nuisance; it therefore obviates the need for a separate external superstructure, and it can thus meet social aspirations for an "inside" toilet at low cost. Wherever space permits, two pits should be built. Then, when the first pit is full, the PF unit can be connected to the second pit. When the second pit is nearly full the first one can be emptied and the toilet connected to it. A PF toilet with alternating pits can be used almost indefinitely.

Material and Labor Requirements

Material and labor requirements for PF toilets shown in Figure 8-17 are similar to those for VIP latrines and ROECs (Figures 8-10 and 8-12). Rather more skill, however, is required to make the water seal units, and this would normally be beyond the scope of individual householders on a self-help basis.

Complementary Investments

Sullage disposal facilities are required for the nonsewered PF toilet.

Water Requirements

Assuming that flushing only takes place when stools are passed and that a maximum of three stools are passed per person daily, the maximum water requirement is 6 liters per capita daily.

Maintenance Requirements

The householder is required to ensure an adequate supply of flushing water throughout the year. Otherwise the maintenance requirements are as described for VIP latrines.

Factors Affecting Suitability

In general PF toilets are subject to the same constraints as VIP latrines and ROECs. They have the additional constraint of a water requirement of 3 to 6 liters per capita daily.

Health

If properly used and maintained, toilets are free from fly and mosquito nuisance and provide health benefits similar to cistern-flush toilets.

Costs

The cost of the PF toilet is similar to that the VIP latrine or ROEC with the addition of the water seal unit. Thus its total construction cost should be in the range of $75 to $225. Maintenance costs of the system would be minimal, but flushing water requirements would probably add $3 to $5 per year for the household in water-scarce areas.

Potential for Upgrading

PF toilets can be easily upgraded to a low-cost sewerage system that also accepts sullage. The necessary design modifications are discussed below. Since the manual PF system can also be eventually replaced by a low-volume, cistern-flush unit, PF toilets can be fully upgraded to sewered cistern-flush toilets.

Potential for Resource Recovery

The pit contents may be used as humus, as described for the VIP latrine. If only one pit is used, however, the material removed from it should be treated before reuse by aerobic composting or by storage (e.g., burial) for at least 12 months in order to reduce the health risks to an acceptable level.

Main Advantages and Disadvantages

The main advantages of unsewered PF toilets are as follows:

(1) possible location inside the house;

(2) no odor or fly and mosquito breeding;

(3) minimal risks to health;

(4) low level of municipal involvement;

(5) low annual costs;

(6) ease of construction and maintenance; and

(7) very high potential for upgrading.

Their main disadvantages are that they require small but nonetheless significant amounts of water (3 to 6 liters per capita daily) and that, when filled, the pit must be emptied or taken out of service and a new one built. They also require separate sullage disposal facilities. They do not accept large bulky items (such as corncobs, mud balls, and the like) used for anal cleansing so that user cooperation and instruction are required in some areas.

Sewered PF Systems

The sewered PF system is a conceptual development of the sewered aquaprivy system that not only overcomes certain drawbacks inherent in the design concept of the latter while retaining its inherent economic advantages, but also provides a more technically appropriate sanitation system in areas where the wastewater flow exceeds the absorptive capacity of the soil (see chapter 14). The sewered PF system can either be developed from an existing PF pit latrine or it can be installed as a new facility. There are minor technical differences between these alternatives and only the latter will be considered in this section.

The sewered PF toilet system has five parts:

(1) the PF bowl, with a vent pipe and inspection chamber;

(2) a short length (8 meters maximum) of 100-millimeter pipe laid at not less than 1 in 40;

(3) a small two-compartment septic tank;

(4) a network of small-bore sewers; and

(5) a sewage treatment facility.

A typical arrangement is shown in diagrammatic form in Figure 8-18. Only excreta and PF water are discharged into the first compartment of the septic tank and only sullage into the second. The two compartments are interconnected by a double T-junction, the invert of which is a nominal 30 millimeters above the invert of the exit pipe of the second compartment, which is connected to the street sewer. Thus the contents of the first compartment are ble to overflow into the second, but sullage cannot enter the first compartment. This arrangement effectively eliminates the very high degree of hydraulic disturbance caused by high sullage flows that, in single-compartment tanks, would resuspend and prematurely flush out some of the settled excreta; it thus permits a considerably higher retention time of excreta in the tank and hence is able to achieve a substantially increased destruction of excreted pathogens.

Guidelines for the size of the two-compartment septic tanks may be developed as follows. Assuming a per capita daily production of excreta of 1.5 liters and a maximum pour-flush water usage of 6 liters per capita daily, the maximum toilet wastewater flow amounts to 7.5 liters per capita daily. Allowing a mean hydraulic residence time of 20 days in the first compartment implies a volume requirement of 0.15 cubic meter per user, which compares well with the recommendation that the first compartment should be calculated on the basis of 0.15 cubic meter per user, subject to a minimum of 1 cubic meter. [1] The minimum recommended size tank (1.5-cubic-meter working volume) is thus suitable for up to seven users and a water consumption of 140 liters per capita daily. Desludging of the septic tank is required when the first compartment is half full of sludge, which occurs every 22 months assuming a sludge accumulation rate of 0.04 cubic meter per person yearly and a capacity of 0.15 cubic meter per user.

Since all but the smallest solids are retained in the septic tank, it is not necessary to ensure self-cleansing velocities of 1 meter per second in the receiving sewers. Small-bore sewers of 100- to 150-millimeter diameter can be used and these can be laid at flat gradients of 1 in 150 to 300. Sullage water ordinarily carries no solids that could clog sewer pipes. Consequently, manholes need only be provided at pipe junctions. Thus the sewered PF system achieves considerable economies in pipe and excavation cost compared with a conventional sewerage system. Taking into account these savings, the extra cost of the small septic tank, the savings in water usage, and the lower cost of the toilet fixtures, the annual economic cost of a sewered PF system can be expected to be considerably less than that of cistern-flush toilets connected to a conventional sewerage system. [2] In addition, treatment costs will be less because of the enhanced pathogen removal and biochemical oxygen demand (BOD) reduction (approximately 30 to 50 percent) in the septic tank.

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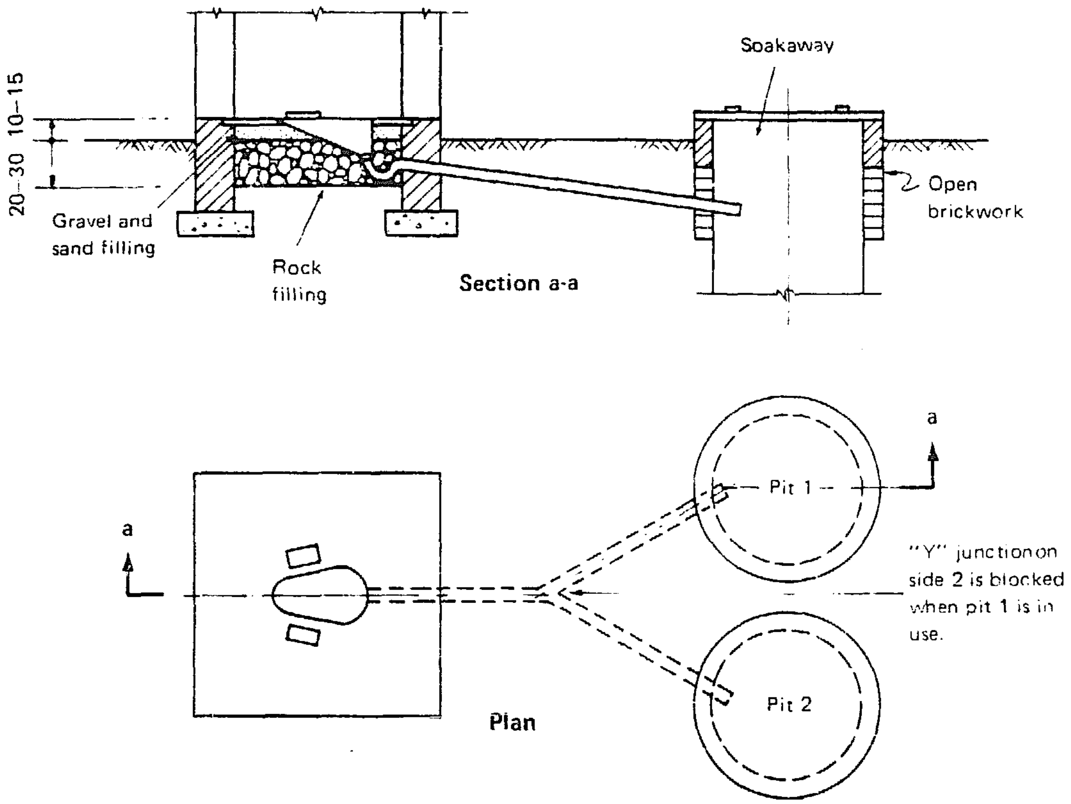
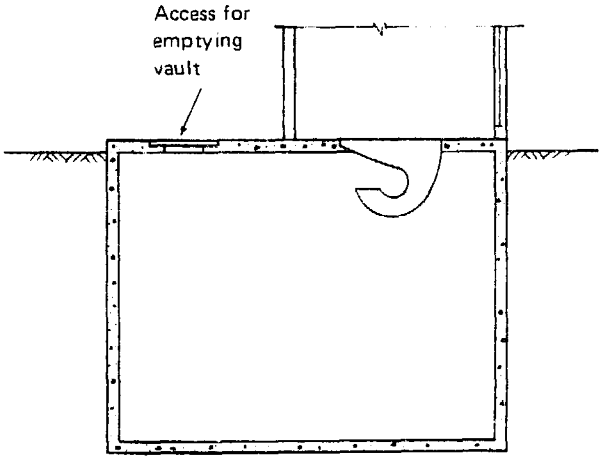
[1] The flow into the second compartment is the sullage flow and the overflow from the first compartment, or, the total wastewater flow.

[2] The magnitude of cost savings is very largely controlled by the gradient. The sewered PF system is most advantageous in flat areas that would necessitate deep excavation and pumping stations for conventional sewerage.

Figure 8-17. Alternative Designs for Pour-flush Toilets (millimeters)



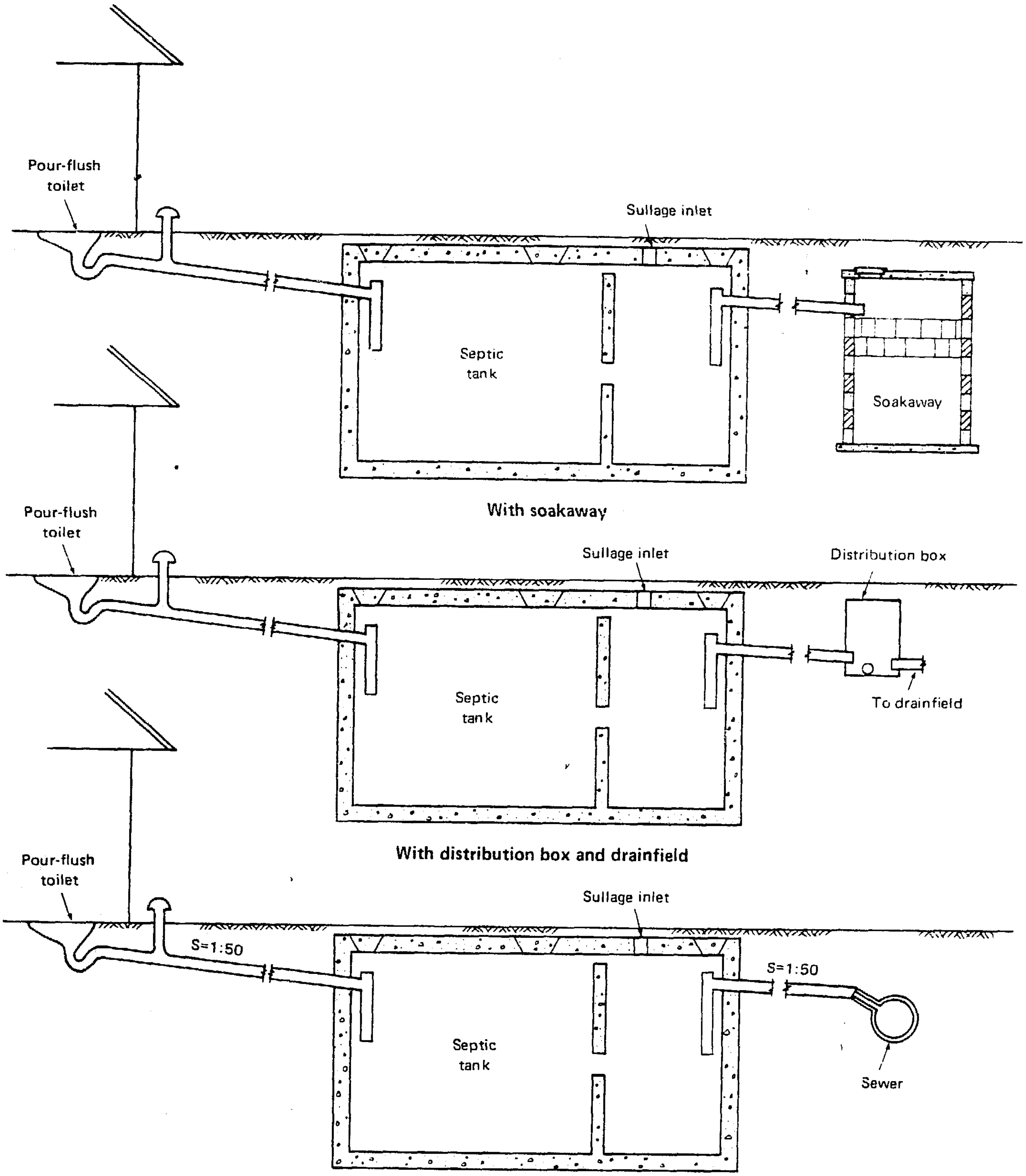
Offset pit design



Direct discharge design

Note: In the offset pit design, the pit is placed at site of "Y" junction if only one pit is installed.

Figure 8-18. Pour-flush Toilet – Septic-tank Systems



With soakaway

With distribution box and drainfield

With sewer

S, slope.

Note: See chapter 14 for details of septic tanks, soakaways, and drainfields.

8.6 Aquaprivies

There are three types of aquaprivies: the simple or conventional aquaprivy, the self-topping or sullage aquaprivy, and the sewered aquaprivy. The second and third types are simple modifications of the first type designed to accept sullage, which the first type cannot.

The conventional aquaprivy toilet (Figure 8-19) consists essentially of a squatting plate situated immediately above a small septic tank that discharges its effluent to an adjacent soakaway. The squatting plate has an integral drop pipe, in diameter 100 to 150 millimeters, the bottom of which is 10 to 15 centimeters below the water level in the tank. In this manner a simple water seal is formed between the squatting plate and the tank contents. In order to maintain this water seal, which is necessary to prevent fly and odor nuisance in the toilet, it is essential that the tank be completely watertight and the toilet user add sufficient water to the tank via the drop pipe to replace any losses. A superstructure is provided for privacy and a small vent pipe is normally incorporated in the design to expell the gases produced in the tank.

The excreta are deposited directly into the tank where they are decomposed anaerobically in the same manner as in a septic tank. There is, as with septic tanks, a gradual accumulation of sludge (approximately 0.03-0.04 cubic meter per user per year), which should be removed when the tank is two-thirds full of sludge. The tank volume is usually calculated on the basis of 0.12 cubic meter per user, with a minimum size of 1 cubic meter. Desludging is normally required every 2 to 3 years when the tank is two-thirds full of sludge. The liquid depth in the tank is normally 1.0 to 1.5 meters in household units; depths of up to 2 meters have been used in large communal aquaprivies.

The volume of excreta added to the aquaprivy tank is approximately 1.5 liters per capita daily, and the water used for "flushing" and maintenance of the water seal is about 4.5 liters per capita daily; thus the aquaprivy effluent flow is around 6 liters per capita daily. The soakaway should therefore be designed on this basis, although it is common to include a factor of safety so that the design flow would be, say, 8 liters per capita daily. The sidewall area of the soakaway should be calculated assuming an infiltration rate of 10 liters per square meter daily.

Technical Appropriateness

Maintenance of the water seal has always been a problem with conventional aquaprivies, except in some Islamic communities where the water used for anal cleansing is sufficient to maintain the seal. Even there, however, it is necessary for the vault to remain watertight. In many other communities people are either unaware of the importance of maintaining the seal or they dislike being seen carrying water into the toilet. If the seal is not regularly maintained, there is intense odor release and fly and mosquito nuisance.

The conventional aquaprivy (Figure 8-19) suffers a major disadvantage: in practice the water seal is rarely maintained. As a consequence it cannot be recommended as a viable sanitation technology option. Although the problem of water-seal maintenance may be overcome in both the sullage and sewered aquaprivies as shown by Figures 8-20 and 8-21, and in spite of the evidence that these two systems have had success (notably in Zambia), the basic design of the aquaprivy system is questionable because of the expensive watertight tank needed to maintain the water seal. Experience has shown that the water seal may not always be maintained (usually because of failure or inadequacy of the water supply), so that the system has a relatively high risk of intermittent malfunction.

As shown in Figure 8-20, the sullage aquaprivy is operationally equivalent to either a VIP latrine (or ROEC) with an entirely separate soakage pit for sullage disposal or a PF latrine with a completely offset pit that can also be used for sullage disposal. The latter alternatives cost less than the sullage aquaprivy and in fact are superior because of their reduced risks of odor and fly nuisance and operational malfunctions. The PF toilet has a much more reliable water seal, which does not require a watertight pit, can be located inside the house, and is more easily upgraded to a cistern-flush toilet.

The logic of the sewered aquaprivy system is similarly questionable. An aquaprivy is sewered not because of any need to transport excreta along sewers, but as a method of sullage disposal in areas where the soil cannot accept any or all of the sullage produced. As shown in Figure 8-21, the sewered aquaprivy can be considered as functionally equivalent to a sewered PF toilet (chapter 8, section 5). The sewered PF toilet is the superior system for the reasons noted above; it is also marginally cheaper.

Thus aquaprivy systems ordinarily cannot be recommended as a viable sanitation option since they can be replaced by technically superior systems at lower cost. One important exception to this, however, is found in areas where the common anal cleansing materials, such as maize cobs, mud balls, and the like, would clog the water seals of PF toilets. In such cases the improved design shown in Figure 8-22 should be used.

Self-topping or Sullage Aquaprivy

The self-topping or sullage aquaprivy was developed to overcome the problem of maintenance of the water seal. In this simple modification of the conventional system with all the household sullage added to the tank; the water seal is thus readily maintained and the sullage is conveniently disposed of. Although the sullage can be added to the tank via the drop pipe, it is more common, and for the user more convenient, for it to be added from either a sink inside or immediately outside the toilet or from one located in an adjacent sanitation block. Naturally, as the volume of water entering and leaving the aquaprivy tank is increased by the addition of sullage, the soakage pit capacity must be increased to absorb a larger flow. Sullage aquaprivies cannot, therefore, be used in areas where the soil is not suitable for soakways or where the housing density of water usage is too high to permit subsurface percolation for effluent disposal, unless the aquaprivy tank can be connected to a sewer system. Since all but the smallest solids are retained in the aquaprivy tank, the sewers can be of small diameter and laid at the nominal gradients necessary to ensure a velocity of around 0.3 meter per second rather than the self-cleansing velocity of 1 meter per second required in conventional sewers transporting raw sewage. Commonly 100- to 150-millimeter pipes are used at a fall of 1 in 150 to 300. Substantial economies in sewer and excavation costs are thus possible, and sewered aquaprivy systems are therefore considerably less expensive than conventional sewerage systems.

Tank Design

The principal modification to the standard aquaprivy tank is the addition of a sullage compartment provided to avoid hydraulic disturbance of the settled excreta in the main part of the tank. The invert of the pipe connecting the two compartments is a nominal 30 to 50 millimeters below the invest of the effluent pipe from the sullage compartment (which leads to the soakage pit or sewer), so that the sullage flow can be used to maintain the water seal in the main compartment, but is unable to resuspend the settled excreta. Since the proportion of excreta in the effluent is considerably less than that in the effluent from conventionally designed aquaprivy tanks, the soakge pit can be smaller as the infiltration rate of the effluent (now mostly sullage) is greater, approximately 30 to 50 liters per cubic meter of sidewall area per day. Thus sewers may not be required as soakage pits can be used for much larger wastewater flows.

The tank volume is calculated to provide 0.12 cubic meter per user in the settling compartment, which should have a minimum size of 1.0 cubic meter. The sullage compartment should have a volume of about 0.5 cubic meter.

Material and Labor Requirements

The aquaprivy vault may be constructed of brick, concrete, or concrete block and must be water-proofed with a stiff mortar. The smaller units may be prefabricated of plastic, if economically feasible.

Self-help labor is suitable for excavation work, but the vault construction requires skilled bricklayers.

Complementary Investments

Aquaprivies require sullage piping to the vault and effluent piping with either an on-site infiltration facility (drainfield, soakage pit, or the like) or off-site sewerage (small-bore or conventional sewers).

Water Requirements

Water required to maintain the water seal depends on local climatic conditions. In the sullage aquaprivy, the amount of sullage water discharged to the privy is sufficient to maintain the water seal, provided all sullage water is drained to the vault. In practice this means that wherever sullage water is used to irrigate a garden, self-topping aquaprivies are not recommended unless water is piped to the house or yard--or the users are educated well enough to maintain the water seal.

Maintenance Requirements

Maintenance is simple. The aquaprivy should be kept clean and the vault desludged at 2-to-3-year intervals. An adequate supply of water is necessary for "flushing" and to maintain the water seal.

Factors Affecting Suitability

Only self-topping aquaprivies should be used and only where a water seal is desired and users have traditionally used bulky anal cleansing materials which would clog a PF toilet. Water is required on-site (yard or house connection) to ensure that enough water is available to maintain water seal.

Health

Properly used and maintained, the self-topping aquaprivy provides health benefits similar to those offered by the cistern-flush toilet.

Costs

Costs of the self-topping aquaprivy can be expected to be higher than eiter latrines or PF toilets because both a pit and a percolation unit are needed. The range of construction cost may be $150 to $400. Maintenance costs would be minimal, though the cost of water could easily reach $5 or more pre year in water scarce areas. Added to this would be the cost of pit emptying every three years, unless the municipality provides this service free.

Potential for Upgrading

Self-topping aquaprivies can easily be upgraded to low-cost (small-bore sewers) sewerage in the manner described for upgrading PF toilets. Similarly, the squatting plate could be replaced by a cistern-flush unit discharging into the vault.

Potential for Resource Recovery

Material removed from the pit should be treated (aerobic composting) or stored for 12 months before use to lower health risk to an acceptable level.

Main Advantages and Disadvantages

The main advantages of the self-topping aquaprivy are:

(i) No danger of clogging by bulky anal cleansing material;

(ii) possible location inside the house;

(iii) no odor or fly and mosquito breeding;

(iv) minimal risks to health;

(v) low annual costs; and

(vi) potential for upgrading;

The main disadvantages are:

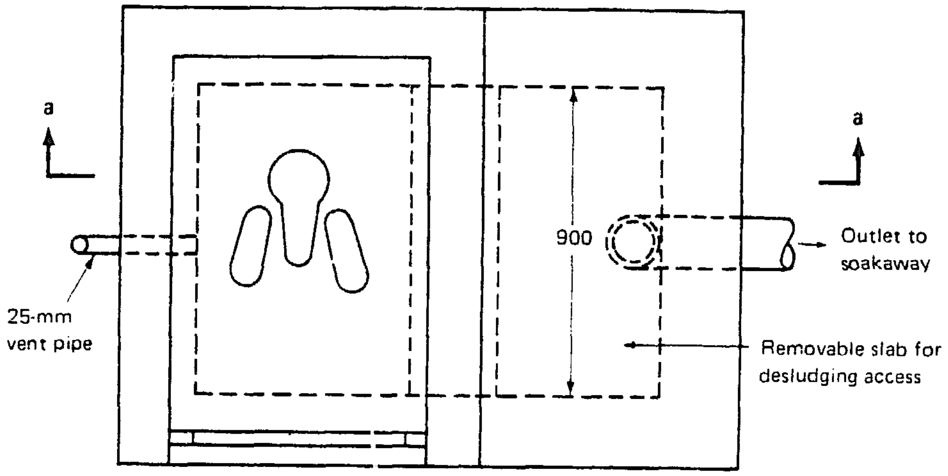
(i) relatively high costs for on-site disposal;

(ii) high level of skill required for construction;

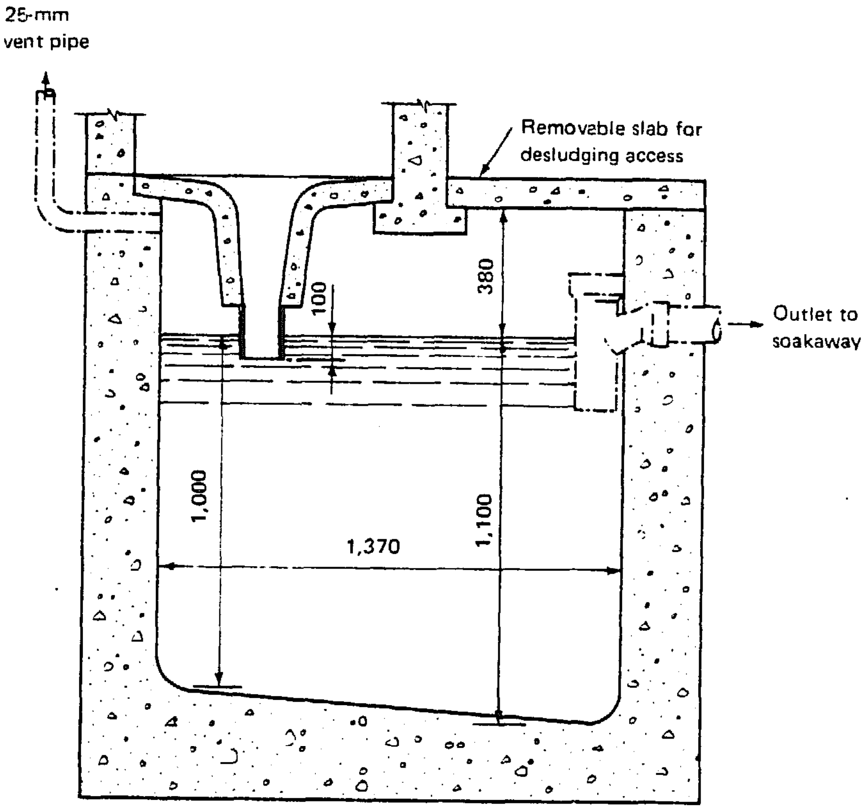
(iii) pit emptying requires some municipal involvement; and

(iv) small but nevertheless significant amounts of water required.

Figure 8-19. Conventional Aquaprivy (millimeters)



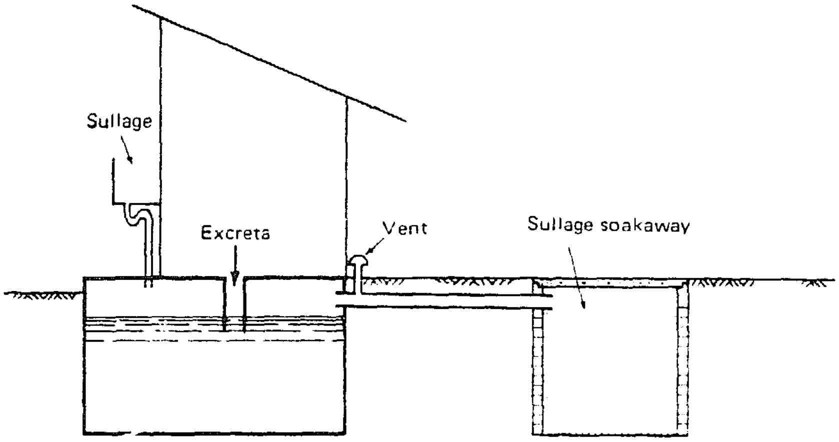
Plan



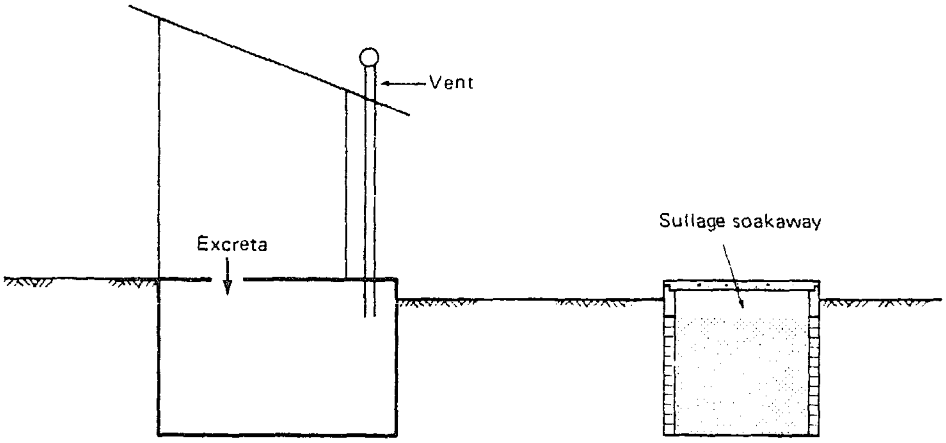
Section a-a

Source: Adapted from Wagner and Lanoix (1958).

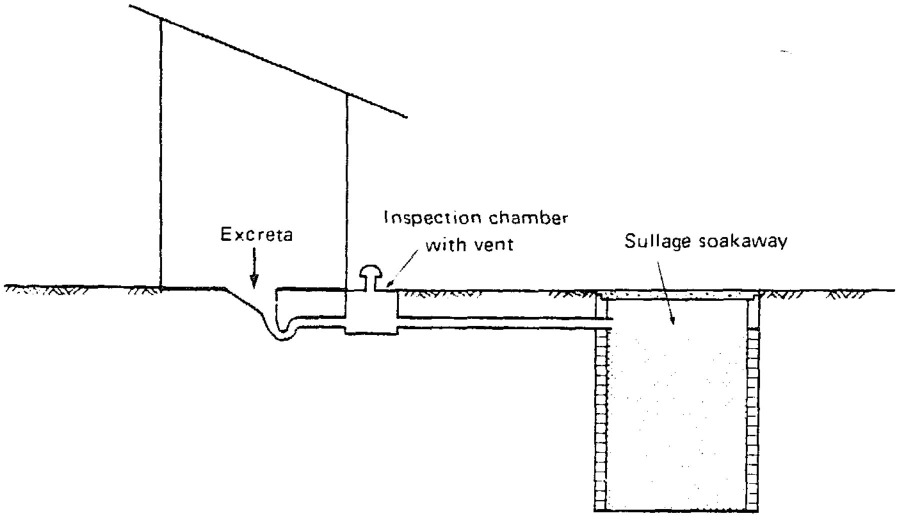
Figure 8-20. Formal Equivalence of Sullage Aquaprivy to Ventilated Improved Pit Latrine with Separate Sullage Soakaway or to Pour-flush Toilet



Aquaprivy

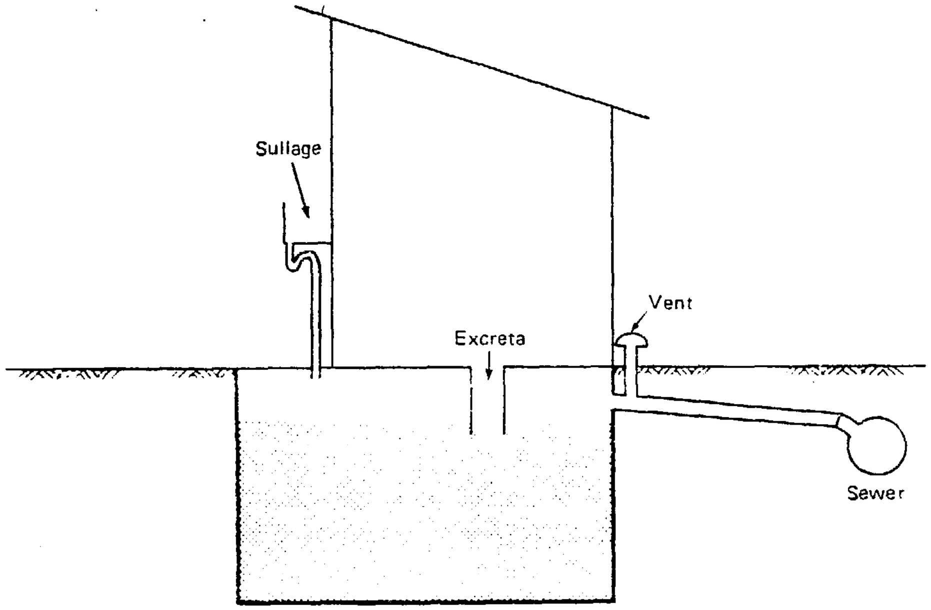


Ventilated improved pit latrine with separate sullage soakaway

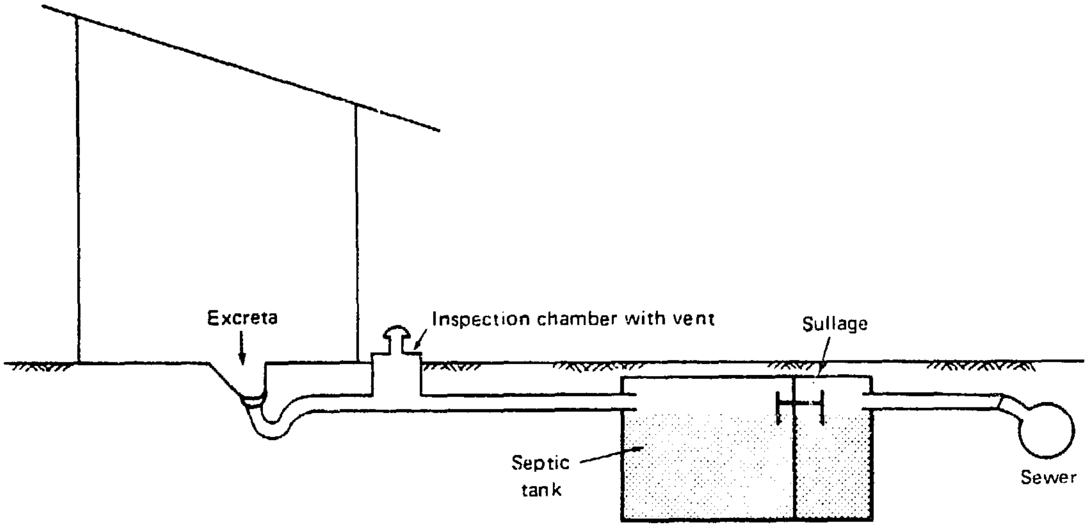


Pour-flush toilet

Figure 8– 21. Formal Equivalence of Sewered Aquaprivy to Sewered Pour-flush Toilet

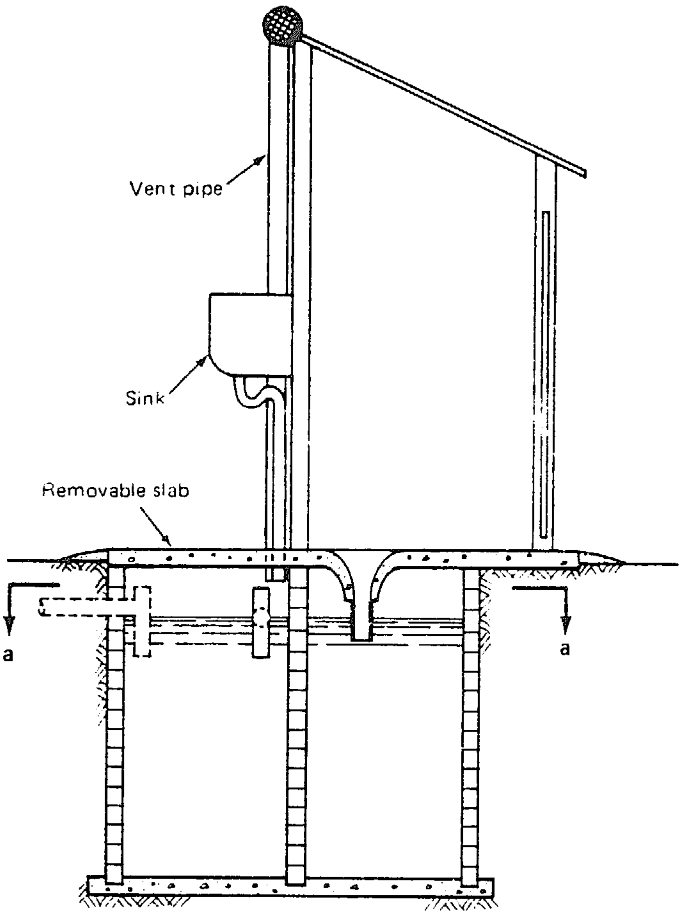


Sewered aquaprivy

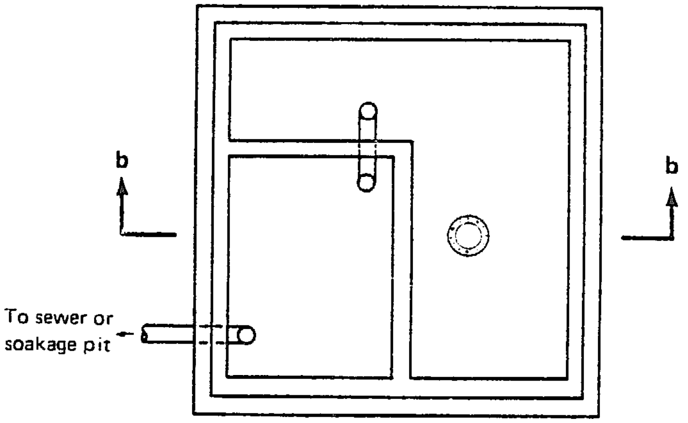


Sewered pour-flush toilet

Figure 8- 22. Improved Sewered Aquaprivy with Sullage Disposal



Section b-b



Plan/section a-a

8.7 Septic Tanks, Soakaways, and Drainfields

Septic tanks are rectangular chambers, usually sited just below ground level, that receive both excreta and flushwater from flush toilets and all other household wastewater. The mean hydraulic retention time in the tank is usually 1 to 3 days. During this time the solids settle to the bottom of the tank where they are digested anaerobically, and a thick layer of scum is formed at the surface. Although digestion of the settled solids is reasonably effective, some sludge accumulates and the tank must be desludged at regular intervals, usually once every 1 to 5 years. The effluent from septic tanks is, from a health point of view, as dangerous as raw sewage and so is ordinarily discharged to soakaways or leaching fields; it should not be discharged to surface drains or water courses without further treatment. Although septic tanks are most commonly used to treat the sewage from individual households, they can be used as a communal facility for populations up to about 300.

A two-compartment septic tank (Figure 8-23) is now generally preferred to one with only a single compartment because the suspended solids concentration in its effluent is considerably lower. The first compartment is usually twice the size of the second. The liquid depth is 1 to 2 meters and the overall length to breadth ratio is 2 or 3 to 1. Experience has shown that in order to provide sufficiently quiescent conditions for effective sedimentation of the sewage solids, the liquid retention time should be at least 24 hours. Two-thirds of the tank volume is normally reserved for the storage of accumulated sludge and scum, so that the size of the septic tank should be based on 3 day's retention at start-up; this ensures that there is at least 1 day retention just prior to each desludging operation. Sludge accumulates at a rate of 0.03 to 0.04 cubic meter per person yearly; thus, knowing the number of users, the interval between successive desludging operations (which are required when the tank is one-third full of sludge) is readily calculated.

Figure 8-24 shows a variety of alternate designs, including an experimental septic tank in which an anaerobic upflow filter is substituted for subsurface systems for effluent disposal. Reports of initial research findings are promising. With 12- to 19-millimeter medium, intermittent flows of 40 to 60 liters per day, and after 90 days maturing, BOD solids removal comparable to or better than those for primary sewage treatment were maintained for 18 months. Further pilot studies may result in general application of this method.

Effluent Disposal

Subsurface disposal into soakaway pits or irrigation in drainfield trenches (soakaways) is the most common method of disposal of the effluent. The soil must be sufficiently permeable; in impermeable soils either evapotranspiration beds or upflow filters can be used, although there is little operational experience with either of these systems. For large flows, waste stabilization ponds may be more suitable (chapter 11).

Drainfield design. The tank effluent is discharged directly to a soakaway (Figure 8-25) or, with larger flows or less permeable soils, to a number of drainage trenches connected in series (Figure 8-26). Each trench consists of open-joint agricultural drainage tiles of 100-millimeter diameter laid on a 1-meter depth of rock fill (20-millimeter to 50-millimeter grading). The effluent infiltrates into the soil surrounding the trench, the sidewalls of which are smeared and partially clogged during excavation. Further clogging of the effluent-soil interface results from slating (hydration) and swelling of the soil particles, from physical movement of fine solids in the effluent into the interface, from chemical deflocculation of clay particles when the effluent water has more sodium than the original interstitial groundwater, and from the formation of an organic mat made up of bacterial slimes feeding upon nutrients in the effluent. This means that the life of a drainfield is limited. Provision must therefore be made to set aside land for use as a future replacement drainfield. Soil percolation tests should be used to determine qualitatively whether or not the soil is sufficiently permeable. The infiltration should not be estimated solely from percolation test results, however, because these merely indicate the infiltration rate of clean water into virgin soil. The infiltration rate that should be used in drainfield design is the rate at which septic tank effluent can infiltrate the soil surface that has become partially clogged with sewage solids (which form an interface between the soil and the drainage trench). This rate of infiltration has been shown to be within the range of 10 to 30 liters per square meter of sidewall area per day for a wide range of soil types. The bottom of the trench is not considered to have any infiltrative capacity since it quickly becomes completely clogged with sewage solids. The trench length required is calculated from the equation:

$$L = \frac{NQ}{2DI}$$

where L = trench length, meters;
N = number of users;
Q = wastewater flow, liters per capita daily;
D = effective depth of trench, meters; and
I = design infiltration rate, liters per square meter daily.

The factor 2 is introduced because the trench has 2 sides. The design infiltration rate for soakaways or drainfields should be taken as 10 liters per square meter daily, unless a more accurate figure is known from local experience.

Soil percolation tests. The soil must have a sufficient percolative capacity. This is determined by conducting percolation tests. A satisfactory field procedure is to drill at least three 150-millimeter-diameter test holes 0-5 meters deep across the proposed drainfield. These are filled with water and left overnight so that the soil becomes saturated; on the following day, they are filled to a depth of 300 millimeters. After 30 and 90 minutes the water levels are measured; the soil is considered to have sufficient percolative capacity if the level in each hole has dropped 15 millimeters in this period of 1 hour.

Location of Septic Tanks and Drainfields

Septic tanks and drainfields should not be located too close to buildings and sources of water or to trees whose growing roots may damage them. Table 8-1 gives general guidelines for location in the form of minimum distances from various features.

Table 8-1: Minimum Distance Requirements for Septic Tanks and Soakaways /a in Common Well-developed Soils

Item	Septic tank (meters)	Soakaway (meters)
Buildings	1.5	3.0
Property boundaries	1.5	1.5
Wells	10.0 /a	10.0 /a
Streams	7.5	30.0
Cuts or embankments	7.5	30.0
Water pipes	3.0	3.0
Paths	1.5	1.5
Large trees	3.0	3.0

Source: Adapted from Cotteral and Norris (1969).

a. Up to 30 meters for sands and gravels; larger values for jointed or fissured rocks. As noted above, drainfields clog up and must be taken out of service periodically to permit their recovery. This is ordinarily done by adding a second drainfield, operating it to the point of refusal, and diverting the flow back to the first one. Alternatively, intermittent discharge of the septic tank effluent will tend to keep the drainfield aerobic and thus increase its operating life. Another alternative to drainfield clogging is an evapotranspiration bed, the area and planting of which is designed from local climatic and agronomic data, particularly irrigation experience (see Figure 8-27).

Technical Appropriateness

Septic tanks of the conventional design described above are indicated only for houses that have both an in-house water supply and sufficient land for effluent disposal. These two constraints effectively limit the responsible use of septic tanks to low-density urban areas. In such areas they are a very acceptable form of sanitation. It is all too common, however, to see septic tanks provided in medium-density areas where the effluent, unable to infiltrate into the soil, is discharged either onto the ground surface, where it ponds, or into street gutters or storm drains; in these cases it causes odor nuisance and encourages mosquito breeding and is a health hazard.

It is possible to alter the design of the septic tank to make it more suitable for use in medium-density areas (up to approximately 200 people per hectare). One design modification is the provision of three compartments (see Figure 8-24); toilet wastes only are discharged into the first compartment and sullage directly into the third; the second compartment provides additional and more quiescent settling for fecal solids. The first compartment should be designed on the basis of 0.15 cubic meter per user, so that desludging is required approximately every 2 years. The second and third compartments should be sized to provide 1 day retention time in each. Since the effluent from the third compartment contains very few fecal solids (which are predominantly responsible for the clogging of drainage trenches receiving conventionally designed septic tank effluents), the infiltration rate of the effluent is much higher, approximately 30 to 60 liters per square meter daily. The trench length is correspondingly smaller and thus septic tanks with soakaways become technically feasible, and the need for sewerage obviated, at higher housing densities than is possible with conventionally designed septic tanks, perhaps as high as 300 people per hectare.

Maintenance Requirements

In order to provide the minimum 24-hour detention time in the first compartment required for proper operation, septic tanks should be inspected periodically to ensure that neither scum particles nor suspended solids are being carried out with the effluent. In any case tanks must be desludged at regular intervals. For example, the 0.04 cubic meter per capita yearly accumulation rate used for designing a septic tank for ten people with a working volume of 1 meter wide, 3 meters long, 2 meters deep, and 1/3 of the volume to provide for sludge and scum accumulation will result in a pumping interval of 5 years.

Factors Affecting Suitability

The main physical factors that affect the suitability of septic tanks are low soil permeability, restricted space for drainage fields, high water service levels, and proximity of wells that supply drinking water.

Health Aspects

In most cases, enteric bacteria do not survive more than 10 meters of travel through soil. Greater travel distances have been observed, but these have been through sandy, gravelly, or fissured overburden. Therefore, if the drainfield is adequate, no health hazard should result. For discussion of groundwater discussion, see chapter 2, Health Aspects of Sanitation.

Costs

Septic tanks and leaching fields are among the most expensive forms of household waste disposal. Capital operation and maintenance costs have been found to exceed costs of conventional sewers and sewage treatment by 50 percent in the United States and to be about equal to the costs of sewerage, including conventional activated sludge with effluent chlorination and sludge incineration.

Upgradability

PF or cistern-flush toilets with septic tank systems are readily connected to small-bore or conventional sewerage systems. The conversion is often required when water use and/or population density exceed limiting characteristics of the soils in which the drainfields are placed.

Resource Recovery

The three-compartment septic tank was specifically designed and operated for recovery of fertilizer from human and animal excreta in rural areas of China. Excreta and the required flushwater are discharged via a PF bowl (or, alternatively, via a straight or curved chute as in an ROEC) into the first compartment of the septic tank. The retention time in this chamber is 10 to 20 days. The contents of the first compartment overflow into the second, to which may also be added animal excreta (especially pig) from an adjacent animal pen. The retention time in the second compartment is also 10 to 20 days; allowance has to be made for the additional daily volume of animal wastes. The third compartment, which receives the effluent from the second, is a treated excreta storage tank with a holding capacity of 20 to 30 days. The contents of the third compartment are removed for use as liquid fertilizer on agricultural crops; alternatively they could be used to fertilize fish ponds.

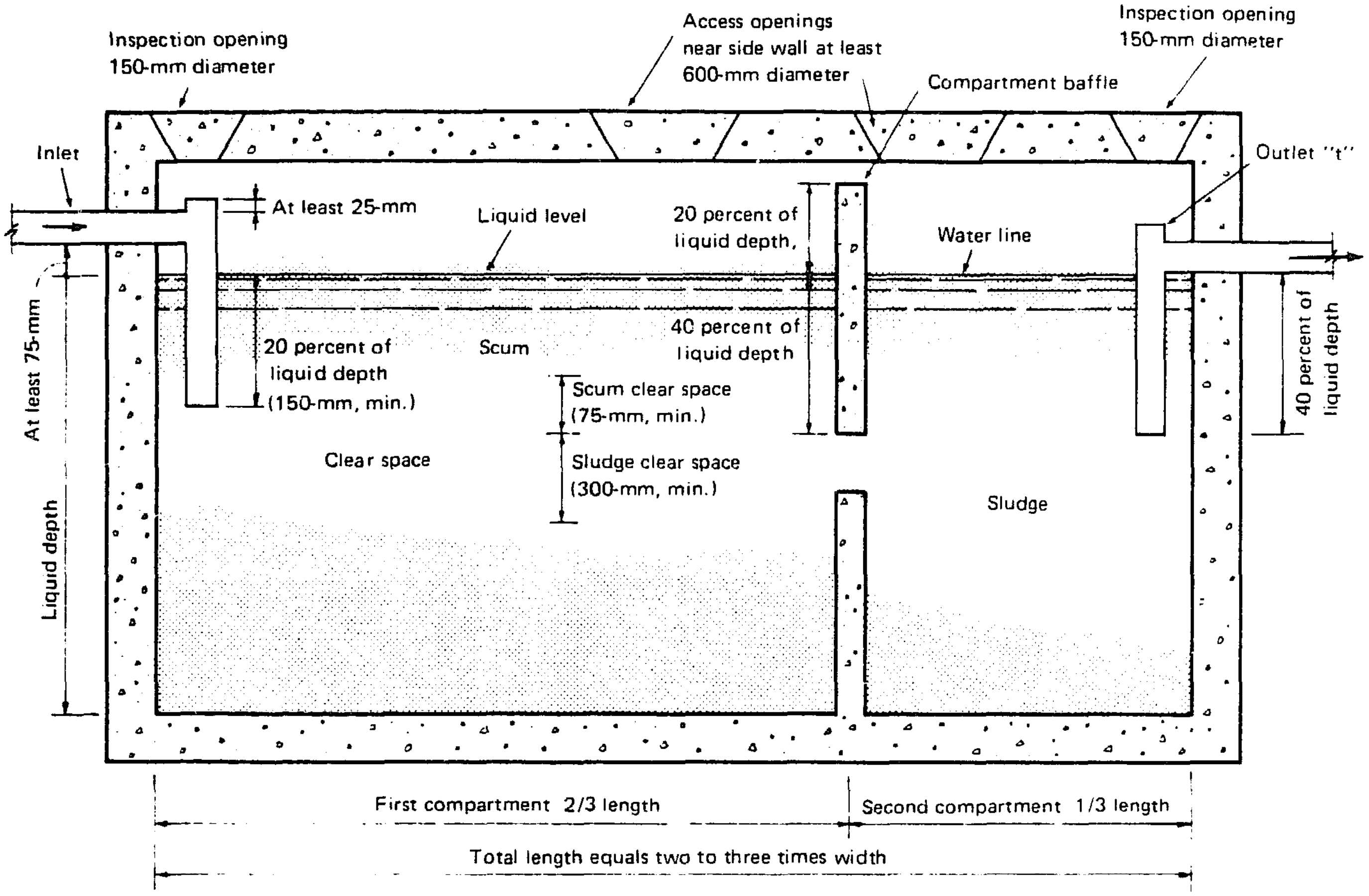
Experience in rural China has shown that the three-stage septic tank system reduces fecal coliform counts to below 1,000 per 100 millimeters and achieves an Ascaris ova removal efficiency approaching 100 percent (with at most 5 percent viability of the few remaining ova). The contents of the third tank are reported to be relatively odorless, light brown to yellow in color, and with only finely divided suspended solids.

During the 40- to 60-day retention time in the septic tank a very high degree of excreted pathogen removal occurs; nonetheless, the final product will contain significant numbers of pathogenic bacteria, viruses, and helminths. There is no doubt that the agricultural reuse of excreta treated in the three-stage septic tank is superior to the direct use of untreated excreta. It is, however, questionable whether in many parts of the world such treatment would be considered sufficient, and whether the reuse of only partially treated excreta is socially acceptable or indeed advisable from the health point of view. The three-stage septic tank system is only applicable to rural areas where there is a tradition of using liquid excreta for crop or fish pond fertilization. In such areas its pathogen removal efficiency can be considerably increased by providing 30 days' retention in each compartment with a corresponding increase in vault volumes. The three-stage septic tank design shown in Figure 8-24, which provides for increased retention and destruction and for introduction of sullage to the third chamber, is a modification of the proven Chinese design.

Main Advantages and Disadvantages

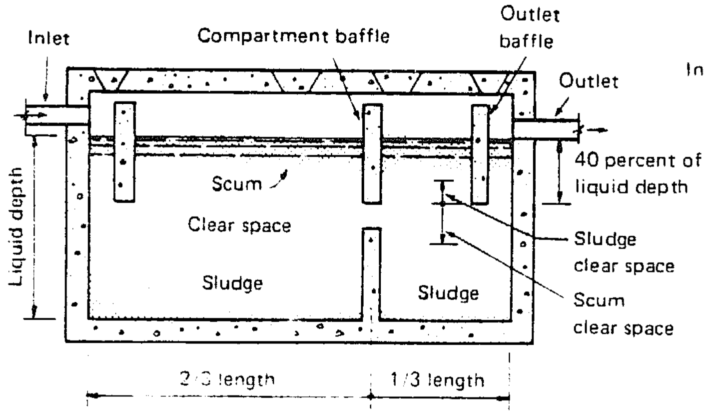
The main advantage of septic tank systems is their flexibility and adaptability to a wide variety of individual household waste disposal requirements. Their major disadvantages include large space requirements, a reasonably high degree of user attention, and high costs.

Figure 8- 23 . Schematic of Conventional Septic Tank (millimeters)

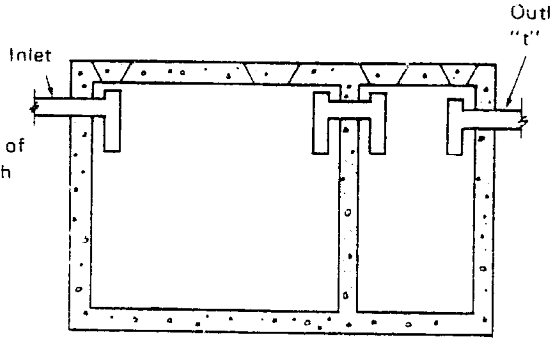


Note: If vent is not placed as shown on figures 13–2, 3, and 4, septic tank must be provided with a vent.

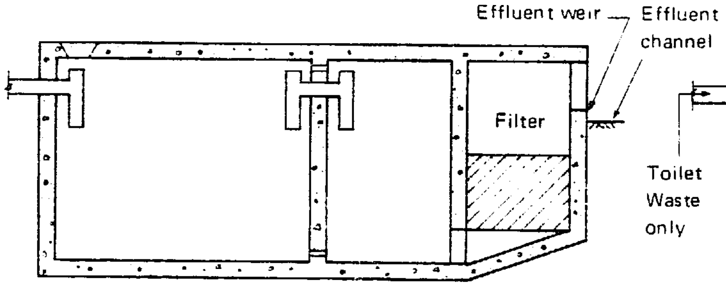
Figure 8- 24 . Alternative Septic Tank Designs (millimeters)



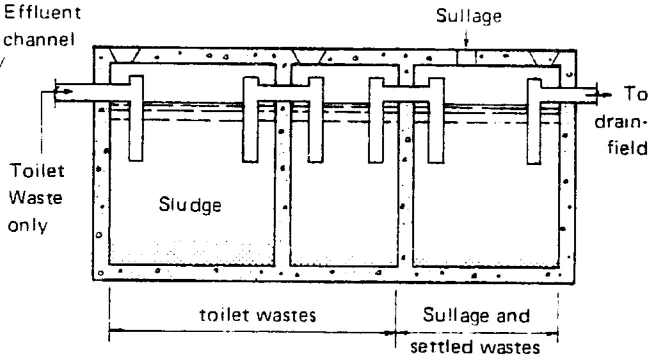
Conventional two-compartment septic tank with baffle walls



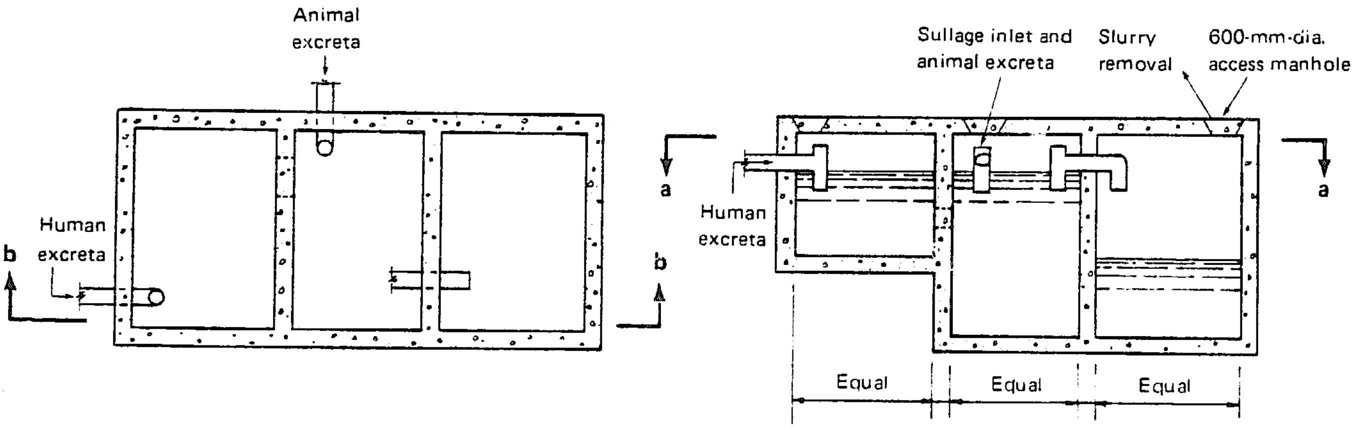
Conventional two-compartment septic tank with inlet connector and outlet "t"



Two-compartment septic tank with upflow filter



Three-compartment septic tank

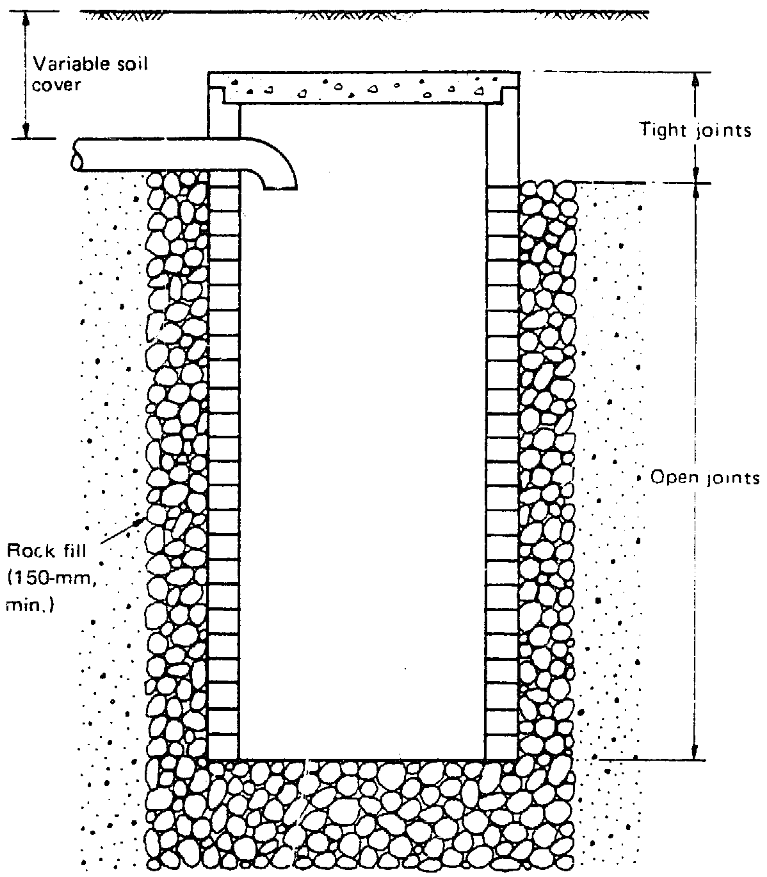


Section a-a

Section b-b

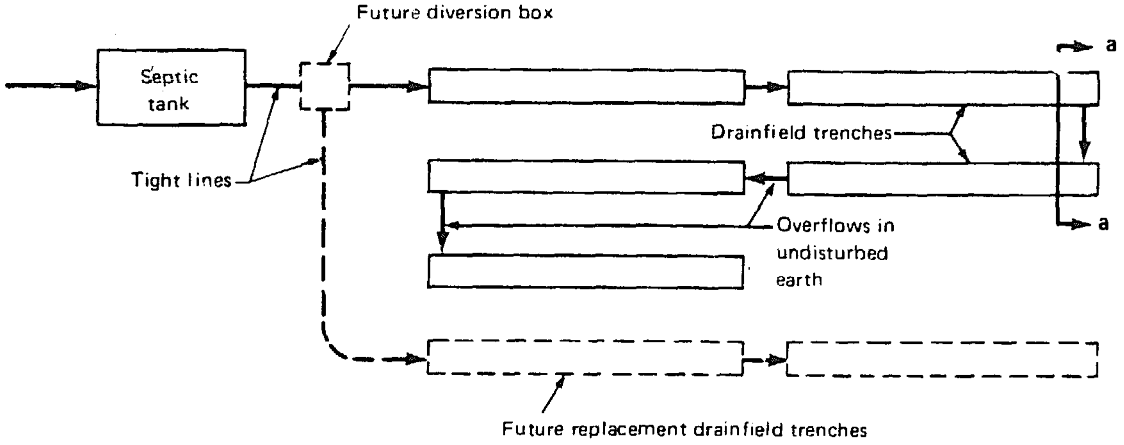
Three-compartment septic tank for resource recovery

Figure 8-25. Schematic of Soakaway (millimeters)

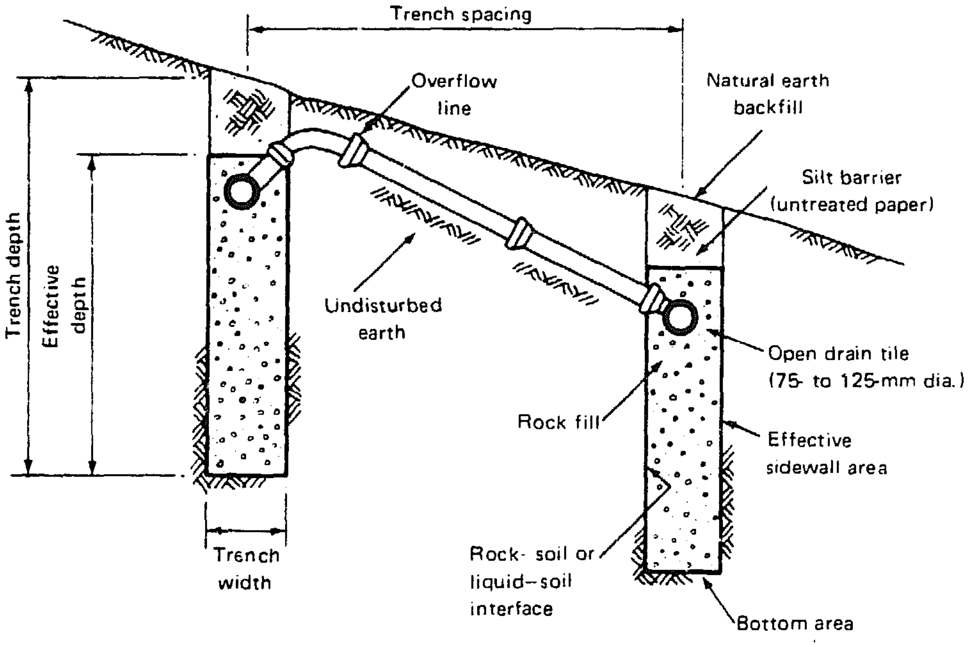


Source: Adapted from Wagner and Lanoix (1958).

Figure 8- 26 . Drainfield for Septic-tank Effluent (millimeters)



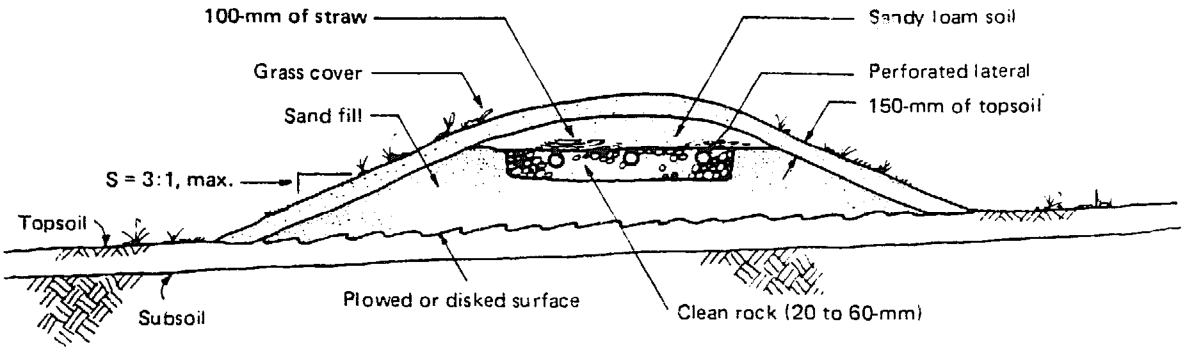
Plan



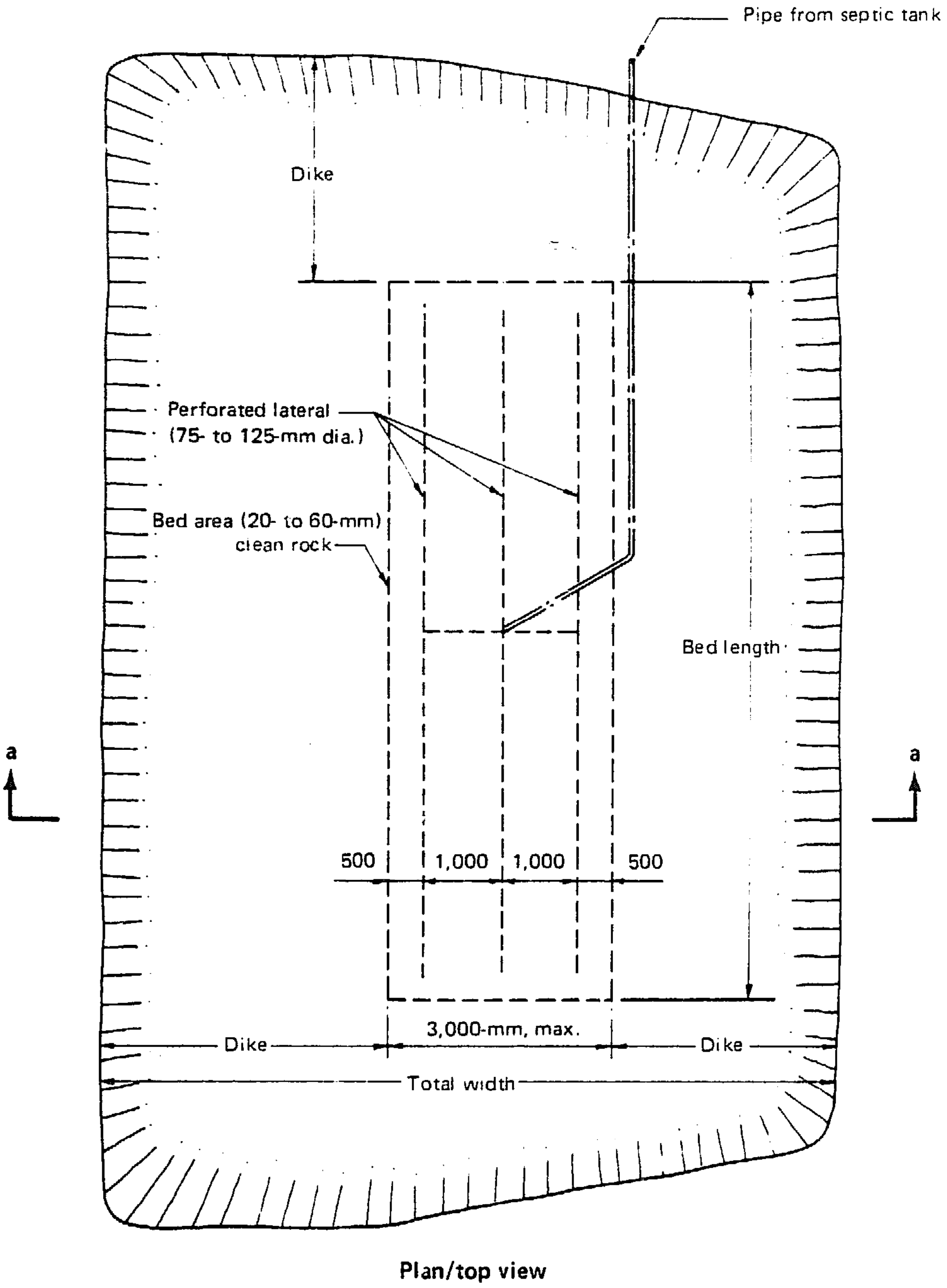
Section a-a

Source: Adapted from Cotteral and Norris (1969).

Figure 8-27. Evapotranspiration Mounds (millimeters)



Cross section a-a



Plan/top view

S, slopes

Note: An acceptable alternative to a mound is an evapotranspiration bed, which has the same construction but is built in a natural or manmade depression not subject to flooding and has a more or less level surface.

CHAPTER 9

OFF-SITE TECHNOLOGIES

9.1 Conventional Sewerage

This section represents a brief overview of conventional sewerage. It is neither an authoritative nor comprehensive treatment, nor is it intended to provide guidance to the designer of conventional sewerage systems. Those interested and requiring further information will find a wealth of publications easily available. The discussion here is intended merely to point out some of the reasons why conventional sewerage is only one of the sanitation alternatives that should be considered in developing country communities.

Excreta Disposal

The conventional cistern-flush toilet is basically a water-seal squatting plate or pedestal unit in which excreta are deposited and then flushed away by 10 to 20 liters of clean, potable water that have been stored in an adjacent cistern; the cistern is connected to the household water supply and is provided with a float valve so that it automatically refills to the correct volume in readiness for the next flush. The excreta and flushwater are discharged, together with all the other household wastewater (sullage), into an underground network of sewers for transport to a sewage treatment works or marine discharge station. Alternatively, in low-density areas they may be discharged into a septic tank (chapter 8, section 7).

Sewage Collection

Conventional sewerage is designed to transport a mixture of excreta and water from the house to the central treatment plant through a network of pipes. Usually this is done in a separate sanitary sewer system that transports only household wastewater, although some cities have combined sewer systems that carry both sewage and stormwater. Nowadays, however, it is customary to build separate sewer systems rather than to provide large combined sewers, the capacity of which is only fully utilized during periods of intense rain and that are likely to have dry weather flows with insufficient velocities to transport excreta.

Sanitary sewer pipes are normally produced from concrete, asbestos cement, vitrified clay, or polyvinyl chloride (PVC). They are generally designed for gravity transport of maximum (peak) flows of 2.5 to 4 times the mean daily flow at velocities of 0.6 to 1.0 meter per second at mean daily flow. This velocity is required to resuspend and transport solid material that may have settled down during periods of lower flows, i.e., lower velocity. In areas where bulky anal cleansing materials are used or where sand is used for scouring kitchen utensils, velocities of not less than 1 meter per second are necessary to prevent blockage of sewers. Achieving such velocities may require fairly steep pipe grades in flat areas. This implies the construction of pumping stations to lift sewage to higher elevations, increasing the cost of sewer systems substantially.

Conventional sanitary sewer systems have many merits; they provide the greatest user convenience of all the waste disposal systems for they permit the discharge of large amounts of water; they do not pose any risks to health when functioning properly, require minimal municipal maintenance and, in general, operate with few service interruptions or emergencies. On the other hand, the systems also have disadvantages: they are, first of all, very expensive to construct; they require skilled contractors for the construction, a municipal organization for operation and maintenance, and a substantial amount of water, which adds to the operating costs. They are not suitable where water supply is limited because they are prone to malfunction (blockage) where total water use is less than about 75 liters per capita daily, and in hot climates, concrete and asbestos cement pipes are subject to rapid deterioration due to sulphuric acid corrosion.

Given the high convenience level of sanitary sewerage, this system of excreta disposal has been the one of choice almost to the exclusion of other alternatives. Unfortunately the usually high costs associated with the construction of such systems have virtually prevented large segments of society from obtaining benefits from this solution. Thus, a search has been on to find ways and means to reduce the cost of sanitary sewerage and make the system affordable to a much greater number of people. Attempts have been made to find new pipe materials, such as PVC, which have reduced the cost somewhat. So far, however, no substitute has been found for the expensive large pipes that are needed for main and interceptor sewers. Other advances made are the introduction of plastic pipes for house plumbing and connections from the house to the street main. Nevertheless, overall costs have remained high and conventional sewerage, therefore, still is beyond the financial capacity of vast numbers of poor people in developing countries.

Conventional Sewage Treatment

The purpose of sewage treatment is the elimination of pathogens, chemicals, organics, and other material that could have a detrimental effect on human health and the environment from sewage prior to its discharge to receiving waters and land.

A variety of unit processes are combined to form a conventional sewage treatment works. Typically these consist of:

(1) preliminary treatment (screening or comminution, flotation, and grit removal);

(2) primary sedimentation;

(3) biological treatment by biofilters (tackling filters) or activated sludge process;

(4) secondary sedimentation; and

(5) treatment of the sludge from the sedimentation tank (commonly anaerobic digestion and drying beds).

Tertiary treatment (microstraining, sand filters, chemical precipitation, and the like) is rarely incorporated in developing countries. Alternative processes for sludge dewatering (such as pressure filtration and centrifuging) are also rarely used in developing countries.

Conventional sewage treatment has three major disadvantages in developing countries:

(1) extremely poor pathogen removal efficiencies (see below);

(2) very high capital and operating costs (usually with the need to import all or much of the mechanical equipment, with a consequently high foreign exchange cost); and

(3) a requirement for a very high level of maintenance skill.

There are many conventional sewage treatment works in developing countries, but unfortunately only a minority operates satisfactorily. The majority is not maintained properly, a problem that is often exacerbated by long delays in importing spare parts and disinfectants needed to destroy pathogens not removed by the treatment process.

Effluents from conventional treatment works (primary sedimentation, trickling filters or activated sludge, and secondary sedimentation) contain significant concentrations of viruses, bacteria, protozoa, and helminth ova and are thus unsuitable for direct reuse in agriculture. They may often be unsuitable for discharge to freshwater bodies where those water bodies are used for domestic water supplies by downstream populations. The minimum hydraulic retention time in the total plant may be only from 5 to 12 hours, which largely explains why the effluent, even if it is of adequate chemical quality (for example, BOD_5 <20 milligrams per liter and suspended soids <30 milligrams per liter) will be of poor micro-biological quality. Effluent quality may be improved by using double filtration or recirculation, but the final effluent will still be highly pathogenic. The only way to produce a reasonably good quality effluent from a health viewpoint is by certain tertiary treatment processes.

The quality of the sludge depends on what treatment it receives. Fresh sludges from primary and secondary sedimentation tanks will contain pathogens of all kinds. Batch digestion at 50°C for 13 days will kill all pathogens, at 32°C for 28 days will remove protozoa and enteroviruses, and for 120 days unheated will remove all pathogens except helminths. Sludge drying on open beds for at least 3 months will be very effective against all pathogens except helminth ova. Other unheated dewatering techniques will have little effect on the pathogenic properties of sludge.

Continuous digestion at 40 to 50°C may produce a sludge with some helminth ova or with enteric bacteria and ova if sludge drying beds are not used. All other alternatives will produce a sludge with helminth ova, and some (such as digestion at 35 to 40^{o}C followed by vacuum filtration) will produce a sludge with enteric viruses and bacteria as well. Thus no sludge digestion and drying process in common use offers any safeguard against pathogens.

The importance of temperature and time for pathogen destruction is shown in Figure 9-1). From a health point of view, the object of a sewage treatment works should be to retain all solids and liquids for the maximum time and/or to heat them to the maximum temperature feasible. Batch processes are far more reliable in achieving this than continuous processes, particularly when the sludge is to be reused in agriculture. Batch digestion of municipal sludges, however, will require both seeding and from 30 to 90 days start-up time to reach effective operating temperatures.

Numerous modifications of the activated sludge process exist. Two are mentioned below because their simplicity makes them especially attractive for application in developing countries. Aerated lagoons resemble small waste stabilization ponds (see chapter 11) with floating mechanical aerators, but they are more correctly considered as a simple modification of the activated sludge process.

Aerated lagoons will, as a result of the longer retention times, achieve better pathogen removal than that obtained in the conventional activated sludge process. In the settling pond there will be complete removal of excreted protozoa and helminth ova, although hookworm larvae may appear in the effluent, which will also contain bacterial pathogens and viruses. Schistosome larvae will be eliminated if the snail host is prevented from infesting the lagoon. The effluent can be treated in one or more maturation ponds to achieve any desired level of pathogen survival.

Oxidation ditches are another modification of the activated sludge process: screened sewage is aerated in and circulated around a continuous oval ditch by one or more special aerators, called "rotors," placed across the ditch. The effluent from the oxidation ditch sedimentation tank has a pathogen content similar to that produced by the conventional activated sludge process, although, as a result of the increased retention time, slightly lower survivals are achieved.

Tertiary Treatment

Tertiary treatment methods are increasingly used in Europe and North merica to improve the quality of effluent produced by conventional secondary treatment works. These processes were not primarily designed for pathogen removal, but some of them do have good pathogen removal characteristics.

Rapid sand filtration is perhaps the most common tertiary treatment method found in larger treatment works. High loading rates (200 cubic meters er square meter daily) and frequent backwashing (1 to 2 days) prevent the uildup of biological activity in the filter. Some viruses will be absorbed nd some bacteria retained. Cysts and ova may be retained because of their ize. In short, the effluent pathogen content may be improved, but not ubstantially, and probably not enough to justify the investment on health rounds.

Slow sand filters may be used on small treatment works because their low loading rates (2 to 4 cubic meters per square meter daily) cause them to occupy a large land area. Substantial biological activity builds up in the upper layers of the filter, and pathogen removal may be very high. Four orders of magnitude removals of viruses and bacteria may be expected from a well-run unit, with viral removal a little higher than bacterial removal. Complete cyst and ova retention have been recorded. Slow sand filters are therefore highly effective in removing pathogens from a conventional effluent but their land requirement makes them suitable only for small treatment works.

Land application is another appropriate tertiary treatment method for small communities. Effluent is distributed over grassland, ideally at a slope of about 1 in 60, and collected in channels at the bottom of the plot. Loadings are in the range 0.05 to 0.3 cubic meter per square meter daily. There is little or no information about this process applied in the tropics or in developing countries. If well managed it should provide a high level of pathogen removal similar to slow sand filters. If poorly managed, it will probably lead to the creation of a foul and insanitary bog.

Lagoons. Conventional effluents can be upgraded in maturation lagoons. The principles involved are exactly as described for waste stabilization pond systems. If two or more maturation ponds are used, with 5 to 10 days retention in each, total removal of cysts and ova will result. Very high levels of viral and bacterial removal are also achieved and, by adding sufficient ponds, a pathogen-free effluent may be produced.

Effluent Chlorination. The chlorination of sewage effluents is practiced in only a few countries (notably North America and Israel). Its purpose is to reduce the high pathogen content of conventional effluents. It has a number of serious limitations, however.

Chlorine has to be applied in heavy doses (10 to 30 milligrams per liter) to achieve coliform effluent concentrations of less than 100 per 100 millimeters. Because viruses have been found more resistant to chlorination than bacteria, doses of 30 milligrams per liter and above have been recommended and, even at these doses, complete viral removal may not be achieved. It is most unlikely that chlorination of effluents will be effective in eliminating protozoan cysts because these are more resistant than both bacteria and viruses. Most helminth ova will be totally unharmed by effluent chlorination.

Thus effluent chlorination--which is not only expensive but also exceedingly difficult to operate uniformly and efficiently--may not be particularly effective in removing pathogens from conventional effluents. Additionally, it may have deleterious consequences for the environment, which include the possible proliferation of carcinogenic chlorinated hydrocarbons.

stage in the sanitation sequences in lieu of conventional sewerage and describe those aspects of design and operation that are different from those of conventional sewerage.

9.2 Small-Bore Sewers

One promising possibility in the search for less expensive sewerage is the small-bore sewer system, which carries settled effluent only. The reduction in cost is possible because such a system requires fewer manholes (access to the underground pipes is primarily to remove blockages in systems that carry solids); pipe slopes can be flatter because scouring velocities to resuspend settled solids (or keep them from settling) are not necessary in a system that does not carry solids; and pipes are laid at shallower depths both because grades are flatter and effluent is discharged from settling tanks close to ground surface.

Small-bore sewer systems require for proper functioning facilities to settle solids, usually at each household or for groups of households. Settling tanks may be septic tanks, soakage pits, vaults, or similar units. Where sullage water is discharged to sewers separately, a sand and grease trap should be provided. Where sand is used for cleaning kitchen utensils, a sand trap should be provided even if sullage water is discharged to a common settling tank because a sand trap can be more easily cleaned than a tank containing a mixture of sludge and sand.

Small-bore sewers are particularly suitable where on-site disposal has been practiced but cannot be continued without modification because infiltration beds are no longer adequate, clogged soakage pits cannot be rehabilitated, or the amount of sullage water has increased to the extent that on-site disposal is no longer possible. In such situations small-bore sewers can provide relief at a lower cost than conventional sewers while providing the same level of service. They can represent, in such a case, the last stage of a planned sanitation sequence. Small-bore sewers should also be considered in the initial planning of a sanitation system in areas where anticipated water consumption or soil conditions make on-site disposal of sullage water infeasible and alternate drainage facilities do not exist.

Design and maintenance parameters based on the few small-bore systems that exist today are summarized below for the guidance of sanitation planners. These guidelines are neither comprehensive nor final and will be modified and updated as more experience is gained. Design of a two-stage septic tank suitable for small-bore systems is described in chapter 8, section 5.

Design Criteria

Minimum Velocity

A minimum velocity of 0.3 meter per second at peak daily flow is recommended. Some flushing of mains may be required until sufficient connections are made. Since in many cases, however, a high density of housing has already been achieved before a public wastewater removal system is considered, especially if small-bore sewers are installed to replace overloaded drain fields, this should at worst be only a temporary problem.

Pipe Sizes

A minimum diameter of 75 millimeters is recommended for connecting mains and septic tanks, aquaprivies, or other settling tanks. Minimum main diameter should be 100 millimeters.

Minimum Grades

The recommended minimum grades are as follows:

75- and 100-millimeter diameter	- 1 in 150
150-millimeter diameter	- 1 in 250
200-millimeter diameter	- 1 in 300

The above grades should not be used as a standard but as the minimum allowable, and greater slopes should be used wherever possible. In general, grades should be maintained fairly accurately. Nevertheless, and in contrast to conventional sewers, slight deviations are permissible because there are no solids that would settle out in a pipe partially filled with standing effluent.

Roughness Coefficient

The adoption of an n-factor of 0.013 for vitrified clay pipe and 0.011 for PVC pipe is recommended. Table 9-1 lists capacities of sewers flowing full at various slopes based on the Manning equation using a roughness factor of 0.011. The table is provided for easy reference for the most suitable and easily handled PVC pipe. For other pipe materials, consult appropriate and easily obtainable hydraulic charts and tables.

Manholes and Flushing Points

Manholes or flushing points should be provided at the heads of all drains and at intervals not greater than 200 meters. Manholes should also be provided at major branch connections and at pipe size changes. Because small-bore sewers are usually laid at shallow depth, it is probably least expensive to construct even fewer manholes initially and install additional manholes as necessary if a main has to be excavated to remove a blockage.

Minimum Cover on Pipes

The minimum cover on all pipes in roadways or areas subject to wheel loads should be 1 meter above the collar of the pipes unless special arrangements are made to protect the pipe from damage. In other situations a general minimum of 0.5 meter, subject to the nature of the terrain and the possibility of mechanical damage, is recommended.

Venting

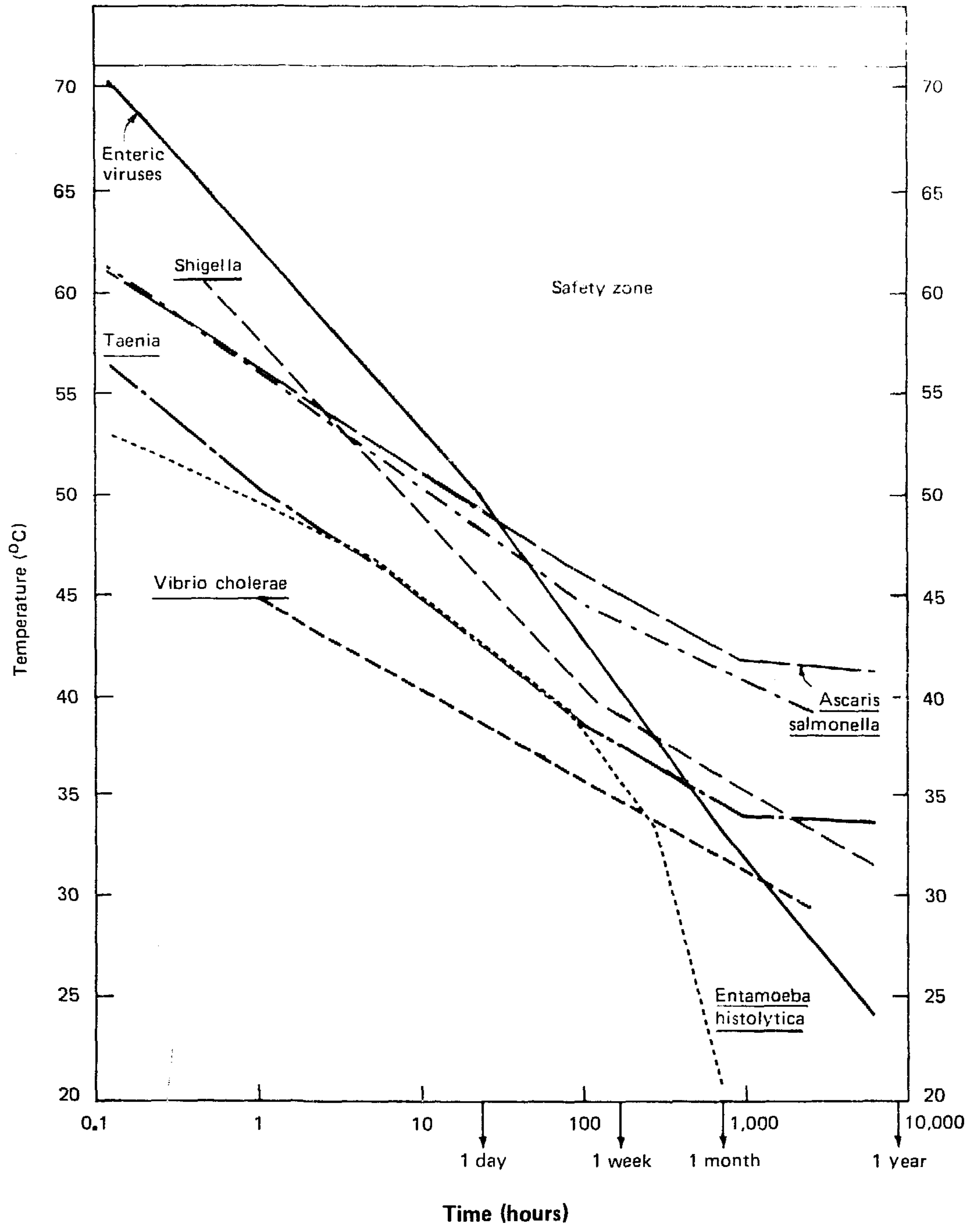
Various methods of venting are applied to sewerage systems, but the most general method in small installations is to use the head vents on the house to provide venting conditions for the reticulation sewers. In the case of a septic tank or aquaprivy system, ventilation is provided between the vent at the outlet of the septic tank, through the air space in the tank, and through the drains to the vent on the house. If a pour-flush privy or toilet is connected directly to the small-bore sewer system, a vent should be provided on the sewer side of the water trap.

Table 9-1: Slopes and Capacities of Circular Pipes Flowing Full

Item	Diameter of pipe (millimeters)					
	50	100	150	200	250	300
Velocity N = 0.3 m/sec						
Slope, m/100 m	0.373	0.148	0.086	0.059	0.044	0.034
Flow, one/sec	0.589	2.356	5.301	9.424	14.726	21.205
Velocity N = 0.6 m/sec						
Slope m/100 m	1.493	0.592	0.345	0.235	0.174	0.136
Flow one/sec	1.178	4.72	10.602	18.849	29.452	42.411
Velocity = 1 m/sec						
Slope m/100 m	4.148	1.646	0.958	0.653	0.485	0.380
Flow one/sec	1.963	7.854	17.67	31.41	49.08	70.68
Velocity = 1.5 m/sec						
Slope m/100 m	9.333	3.703	2.157	1.470	1.092	0.856
Flow one/sec	2.945	11.78	26.50	47.12	73.63	106.03

Note: Calculations are based on Manning equation with roughness coefficient of 0.011.

Figure 9 1 Influence of Time and Temperature on Selected Pathogens in Night Soil and Sludge



Note: The line represents conservative upper boundaries for pathogen death--that is, estimates of the time-temperature combinations required for pathogen inactivation. A treatment process with time-temperature effects falling within the "safety zone" should be lethal to all excreted pathogens (with the possible exception of hepatitis A virus-- not included in the enteric viruses in the figure--at short retention times). Indicated time-temperature requirements are at least: 1 hour at ≥62°C, 1 day at ≥50°C, and 1 week at ≥46°C.

Source: Feachem and others, Sanitation and Disease.

9.3 Bucket Latrines

Technical Description

The traditional bucket latrine (Figure 9-2) consists of a squatting plate and a metal bucket located in a small compartment immediately below the squatting plate. Excreta are deposited into the bucket, which is periodically emptied by a night-soil laborer or "scavenger" into a larger collection bucket, which, when full, is carried to a night-soil collection depot; from there the night soil is normally taken by tanker to either a trenching ground for burial or to a night-soil treatment works.

Improved bucket systems provide satisfactory service in parts of Australia and Singapore. Here full creosoted household buckets are replaced by clean ones, removed, covered, carried by truck to central stations, emptied, washed, creosoted as necessary, and returned to service. Other bucket latrine systems are widely used in Africa, the Indian subcontinent and the Far East where, in contrast, they are generally only emptied. It is, however, an extremely poor form of sanitation; at best, it is better than no sanitation at all. The following two quotations (the first from Africa, the second from India) illustrate the usual unhygienic nature of the system:

> The collection and disposal of night soil from bucket lavatories is usually nauseating. Although in some cases the buckets are manually carried long distances to the disposal ground, the usual practice is to empty the buckets into handcarts, each comprising an empty drum supported horizontally across two wheels; when full, the handcarts are dragged away and (the contents) either buried or emptied into a sewer, septic tank or local depression. Only rarely are the buckets and handcarts washed after use; spillage of night soil is frequent and health hazards are alarmingly obvious. The bucket lavatories are rarely disinfected. They are almost always unhygienic, offensive and usually surrounded by insects, many of which help spread human diseases; sometimes a degree of cleanliness is unintentionally achieved by keeping poultry which devour these insects. 1/

> It is common to see a scavenger moving with a heavy load of night soil on his/her head in a bamboo basket or leaky drum, the contents trickling over the carrier. 2/

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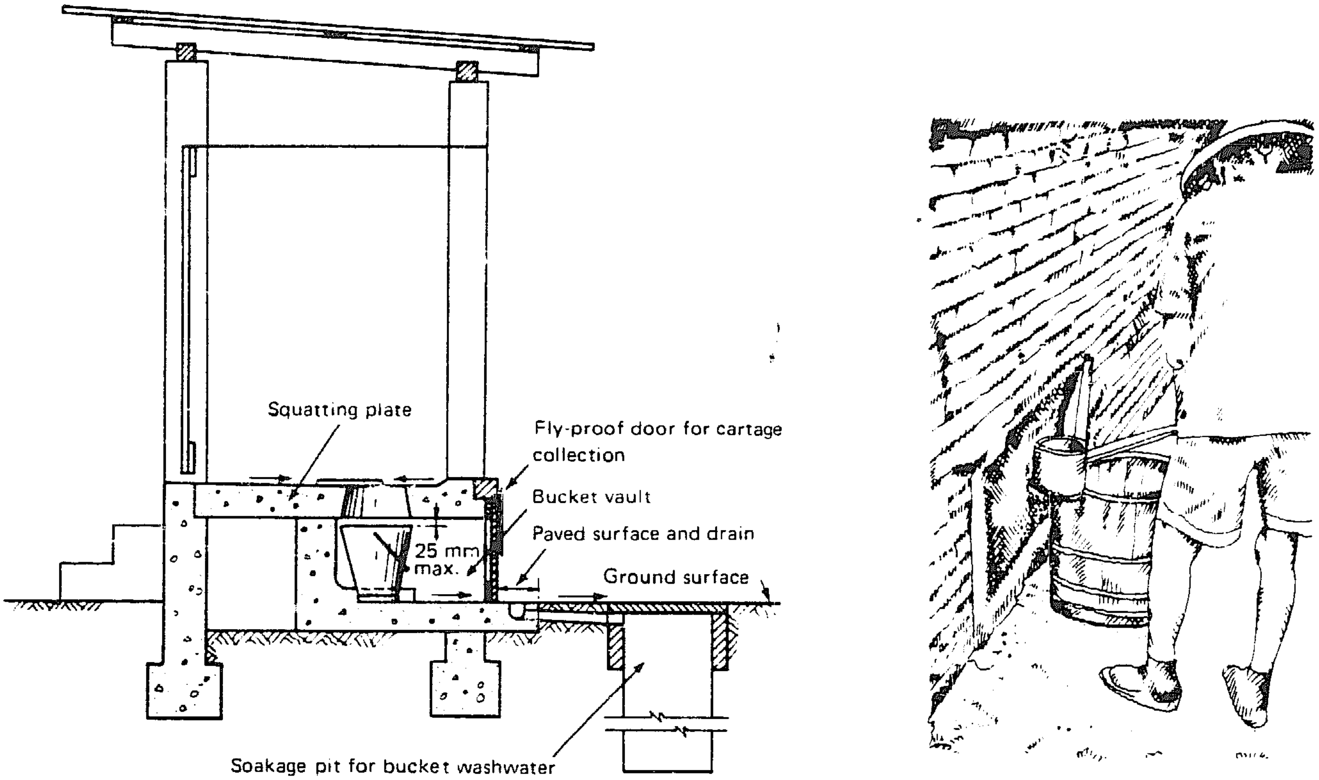
1. Mara (1978).

2. National Environmental Engineering Research Institute (1972).

Although it is possible to make several improvements to the normal bucket latrine system (for example, by providing facilities for washing and disinfecting the buckets, and covering collection buckets with tightly fitting lids to reduce spillage), it is still in practice difficult, if not impossible, to ensure that the system is operated satisfactorily, especially to avoid spillage of night soil. The bucket latrine system, even if it is an improved bucket latrine system, is not a form of sanitation that can be recommended for new communities. Existing bucket latrines should be improved as a short-term measure only; in the long term they should be replaced by some other sanitation facility. Often the most appropriate replacement facility, especially in high-density areas, is the vault toilet (chapter 9, section 4).

Figure - 2. Bucket Latrine and Cartage (millimeters)



Bucket latine

Night-soil collection by dipper and bucket

(here a vault rather than a bucket is located in house)

Night-soil bucket and scraper

Cartage wheelbarrow for three or six buckets

Note: Fly-proof doors and paved surfaces and drains are commonly missing in most existing bucket latrines

Sources: Top, adapted from Wagner and Lanoix (1958); bottom, adapted from Department of Social Welfare, Ahmadabad, India.

9.4 Vault and Cartage Systems

Vault toilets, which are extensively used in the Far East, are essentially similar to the PF toilets (chapter 8, section 5) except that the excreta are discharged into a sealed vault that is emptied at regular intervals (Figure 9-3). Preferably the vault should be emptied by vacuum tanker (vacuum truck refers to tank-truck equipped with regular pump or vacuum pump), although in areas where access is difficult it may be necessary to use alternative methods (see below).

The vault toilet may be installed as a PF toilet either with the vault immediately below the squatting plate or with a completely offset vault (Figure 9-3). In the latter case the vault may be shared between adjacent houses, with some savings in construction costs.

The vault volume may be calculated from the following equation:

$$V = N\,Q\,D/K,$$

where V = vault working volume, liters;

N = average household size;

Q = excreta and PF water flow, liters per capita daily;

D = the number of days between successive emptyings of the vault;

K = vault volume underutilization factor.

From 0.8 to 1.8 liters per capita daily of night soil are collected from vault latrines. The maximum probable combined excreta and PF water flow for vault latrines may be estimated as 10 liters per capita daily. The vault volume underutilization factor, K, is introduced since the vault will normally be emptied before it is completely full. In areas where tanker vehicle maintenance is excellent, K may be taken to be 0.85; in other areas K may need to be as low as 0.5.

It is evident from the above equation that V and D are proportional to each other. Once vault construction and emptying costs are known, it is therefore possible to minimize the total cost by optimizing the combination of vault size and emptying frequency. It is worth noting that the vault need not be very large; for example for a family of six using a 10 liters per capita daily PF system, if the vault is emptied every two weeks and K is taken as 0.5, the required vault volume is only 1.68 cubic meters and 0.84 cubic meter of night soil must be removed each time the vault is emptied.

The tankers transport the vault contents to a trenching field, a night-soil treatment works (chapter 11), or a marine discharge point. If small tankers or other collection vehicles (see below) are used, it may be necessary to provide transfer stations where the night soil is transferred to larger vehicles for conveyance to the treatment works or discharge point in order to minimize vehicle haulage distances and hence collection costs. Transfer stations generally should be used where the treatment works or when discharge point is located long distances away from the collection areas, although conditions are highly site-specific and it is not possible to state in general terms distances at which transfer stations become economical.

Collection Vehicles

In order to minimize collection costs, the night-soil collection vehicles generally should be as large as possible. Vacuum tankers usually have capacities of 1,500 to 5,000 liters, and the length of vacuum tubing that can be attached to them can be as much as 100 meters. In areas where access is difficult even this length is insufficient and smaller collection vehicles must be used. These may be hand- or animal-drawn carts with capacities of only a few hundred liters equipped with manually operated diaphragm pumps, or small mechanically or electrically operated vehicles (even three-wheeled vehicles) fitted with mechanically operated pumps. Since vault toilets are so much cheaper than sewerage (see volume I of this series), it is extremely important that design engineers should consider all possible collection methods, even though this may usually mean that some site-specific improvisation is required. Access may be extremely difficult but only very rarely will it be impossible for any sort of vehicle to be used to empty the vaults. For those households where this may occur, manual emptying of the vault by the dipper and bucket method may have to be used; this, however, is only a marginal improvement in collection practice over bucket latrines as some night-soil spillage is inevitable. A pipe connection to an accessible communal vault would be a preferable solution in such cases.

Material and Labor Requirements

The vault may be constructed from concrete, brick, or concrete blockwork suitably rendered with a stiff mortar to make it watertight; alternatively, for small vaults, prefabricated plastic tanks may be used if these are locally made and economically competitive. Note that loss of water from a vault latrine (Figure 9-3) may cause pumping problems; vault contents with more than 12 percent solids may have to be scooped or ladled. The number of tankers (or other collection vehicles) may be estimated from the following equation:

$$N_t = 7 \frac{Nv}{nD} ;$$

where N_t = number of tankers required;

N_v = number of vaults to be serviced.

v = average number of vaults that 1 tanker can service per day;

n = average number of days that the tankers can be expected to be operational each week;

D = the number of days between successive emptyings of each vault.

The average number of vaults that a tanker can service each day depends on the tanker size to vault size ratio, the average distance of the tanker depot and disposal point or treatment works from the vaults to be serviced, the average time taken to empty one vault, the average distance between vaults, and the speed of the tanker. The average number of days that each tanker is operational each week depends on how many days per week vaults are emptied (usually 5 or 6) and how many days per week are on average required for tanker maintenance (at least 1, especially if adequate stocks of spare parts are not maintained locally); thus, in practice, n may be as low as 3 to 4 days or as high as 5. If transfer stations are used, fewer collection tankers will be required. The number of transfer vehicles depends on the ratio of their size to that of the primary collection vehicles and the number of round trips they can make each day to the discharge station.

Labor requirements for vehicle operation are one driver and in practice (although this is not absolutely essential) one laborer per tanker. Additionally, tanker maintenance mechanics are required.

Complementary Investments

Facilities for the treatment and disposal of the vault contents and for sullage disposal are required (chapters 10 and 11). Additionally adequate facilities for tanker (or other collection vehicle) maintenance must be provided.

Water Requirements

Water is required (approximately 3 to 6 liters per capita daily) for PF toilets. In addition, adequate tanker washwater should be available at the treatment site or at the treatment works or marine disposal point.

Factors Affecting Suitability

The vault toilet, emptied by mechanically, electrically, or manually operated tankers, is an extremely flexible form of sanitation--a characteristic that is highly desirable from the point of view of urban planning, since changes in urban land use are simply handled by redefining the collection tanker routes.

Vaults are also suitable for medium-rise buildings as excreta can be readily flushed down a vertical pipe into a communal vault at or below ground level.

In most developing countries, foreign exchange is required to pay for the collection tankers or pumps. All other materials are likely to be locally available.

Health Aspects

From the users' point of view, there is little difference between vault and PF toilets, the only area of increased risk being the very small amount of night-soil spillage that may occur when the vault is emptied.

Cost

Since the vault is usually located inside or immediately adjacent to the house, superstructure costs may be minimal. The vault itself is relatively small, although skilled labor usually is required to ensure that it is properly sealed. The total cost of the vault with PF squatting plate, vent pipe, and superstructure is in the range of $75 to $200, depending mostly on superstructure costs. The collection and treatment costs associated with vault toilets vary widely depending on the type of collection vehicle used and the type of treatment selected.

Potential for Upgrading

Vault toilets may be converted to sewered PF toilets (chapter 8, section 5) if at some stage in the future it is desired to improve facilities for sullage disposal or sewer lines are laid in the vicinity.

Potential for Resource Recovery

Vault toilets have high potential for resource recovery: the night soil may be used for composting (often with domestic refuse), fish-pond fertilization or biogas production (chapter 12).

Main Advantages and Disadvantages

The principal advantages of vault toilets are as follows:

(1) low initial costs, with system capacity closely matched to demand (trucks can easily be added as housing density increases);

(2) high labor requirements, with consequent employment generation;

(3) low risks to health;

(4) minimal water requirements;

(5) possible location within the house;

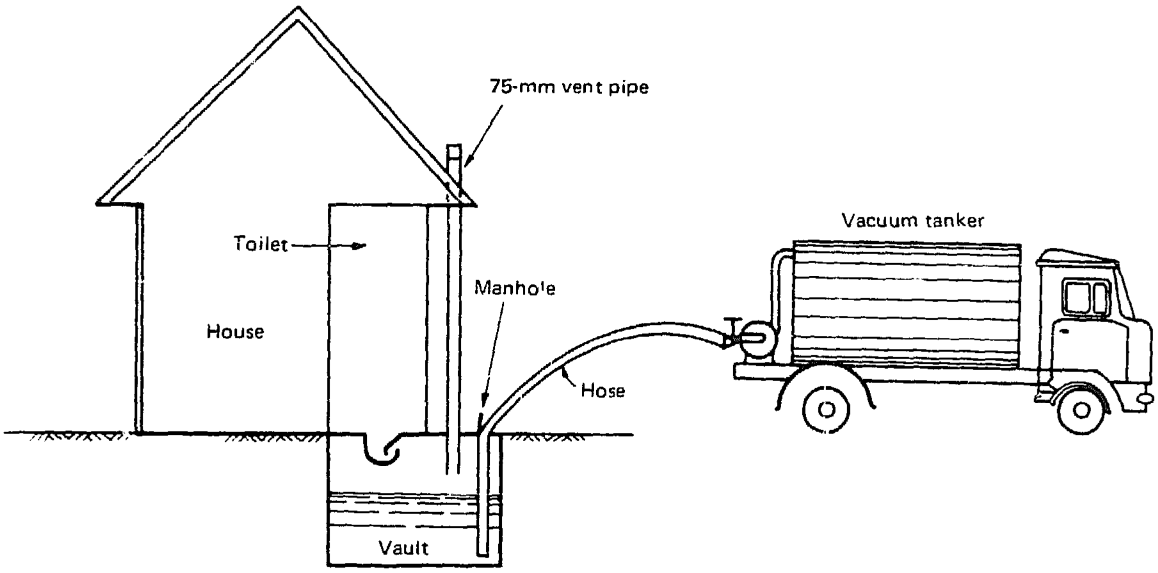
(6) high degree of planning flexibility;

(7) suitability for high-density areas; and

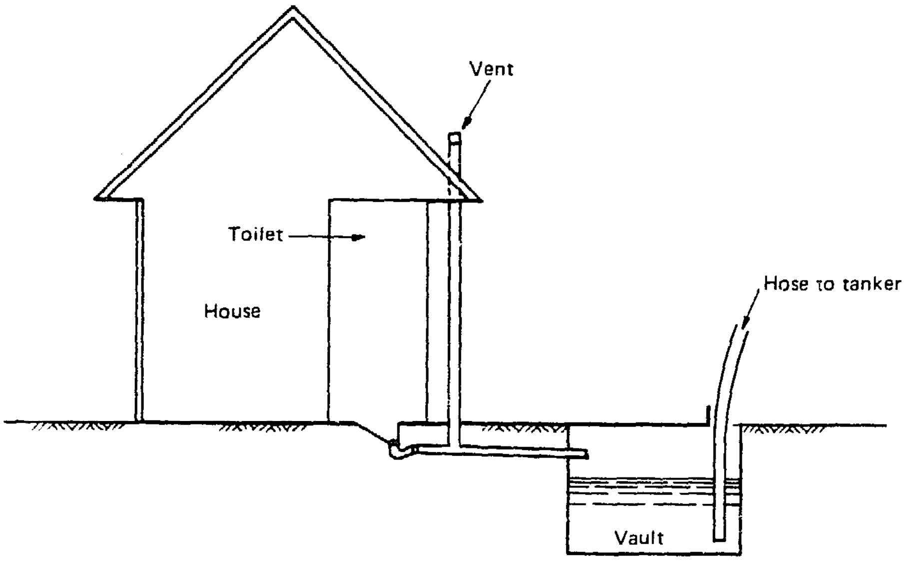
(8) high potential for resource recovery.

Their main disadvantages are that separate facilities for sullage disposal are required, foreign exchange is required for the collection vehicles, and a very high degree of municipal involvement is required to ensure equitable service and proper vehicle maintenance. In cities with proven records of institutional incompetence (which can often be measured by even a cursory examination of any existing bucket latrine collection system), it may be possible to contract out servicing of the vaults to private firms that have a profit incentive to operate the system satisfactorily, especially if the rights to (and profits from) resource recovery are given to the same firm. Alternatively, training of municipal management and personnel along with institutional changes may be necessary.

Figure 9- 3. Alternative Designs for Vault Toilets (millimeters)



Vault below squatting place



Offset vault

9.5 Communal Sanitation Facilities

Advantages and Disadvantages

Communal sanitation facilities provide a minimum service level ranging from sanitation only to a combined latrine/ablution laundry unit. Two such units are illustrated in Figures 8-1 Part B and 9-4. Their principal advantage is their low cost. Because they serve many people they are substantially cheaper on a per capita basis than individual household facilities. They have many disadvantages, however, and the decision to install communal facilities is one that should never be taken lightly. The basic problem with a communal facility is that it appears to belong to no one so that there is very little commitment by individual users to keep it clean and operating properly. Once a toilet compartment is fouled, the next user may have no choice but to foul it further. As a result many communal toilet blocks are in a very unhygienic state. To avoid this it is essential to provide one or more well-paid attendants to keep the facilities in good operational order, and lighting and a water supply must also be provided. It is also essential that the employers of the attendants (often the municipality) should regularly inspect the facilities to make sure that they are being properly maintained.

Technical Appropriateness

There are four technical disadvantages of communal sanitation facilities. First, there is the difficult question of privacy. A community's requirements for privacy must be clearly understood and respected. Cultural attitudes toward defecation vary, but generally it is regarded as a private personal act. Thus, at the least, each toilet within the communal block should be designed as a separate compartment and provided with a door that can be bolted; this may appear obvious, but there are many public toilet blocks that merely contain a row of holes with no internal partitioning whatsoever. In some societies, however, privacy is not so highly coveted. It is clear that questions of privacy must be discussed with the community by the program behavioral scientist (chapter 3). Second, there is the problem of defecation at night and during illness and wet or cold weather. If the communal block is not lit, it may not be used at night. In any case it is surely unreasonable to expect even fit adults--let along the young, the old, or the infirm--to walk 100 meters or more in the middle of the night or in torrential rain, often along a dark or muddy street or alleyway. There must be some general provision (including guidance to the community) for the disposal of nocturnal and "bad weather" excreta.

If it is accepted that the provision of individual household facilities (of whatever type) is the ultimate objective of sanitation program planning, then the third disadvantage of communal facilities is that they cannot be upgraded. This means that they should be designed with eventual replacement by individual household facilities in mind. In this connection it is sensible to tie the provision of sanitation facilities to residential upgrading programs; this is especially advisable in the case of slum improvement schemes.

The fourth disadvantage of communal facilities is their space requirement. Depending upon the type of excreta disposal and the service level provided (see below), this space may vary from 5 to 10 percent of the total land space.

Communal Facilities Design

There are basically two approaches to the design of communal sanitation blocks. The first is to have a truly public system in which a user can enter any toilet compartment not in use at the time. The second approach is to provide within the communal block cubicles for the exclusive use of one household. This system, essentially a compromise between public and private facilities, has been tried with considerable success in some parts of India; experience has shown that each household will zealously guard its own cubicle and keep it clean but that maintenance of the communal parts (e.g., the passageways and particularly the effluent disposal system) can cause organizational problems. This system is undoubtedly superior to the truly public system, but it is also more expensive since a greater number (depending on the average household size) of toilet compartments is needed. The advantage to the municipality is that it is relatively easy to levy rental fees and collect payment from each household using the facility.

A third approach to the design of communal facilities is to provide a sanitation block of the first type but reserved for the exclusive use of a large kinship group. This has been tried with some success in the densely populated old city of Ibadan, Nigeria. Individual households that belong to a patrilineal kinship group, locally termed an "extended family," of between 100 and 1,000 members are located on the same piece of land, which is held in communal ownership by the kinship group. Each kinship group is (or is planned to be) provided with a "comfort station," essentially a communal sanitation block with toilets, showers, and laundry facilities. Part of the construction cost is borne by the extended family and part by the government; the family is responsible for maintenance and also for paying the water and electricity charges. Clearly this approach to the provision of communal sanitation facilities can only work under suitable social conditions. The success of the Ibadan comfort stations has probably been due more to their social setting than to their technical design.

Number of toilet compartments required

In the truly public communal sanitation block, the best available evidence suggests that one toilet compartment can serve twenty-five to fifty people. Although it seems prudent to take a design figure of twenty-five users per compartment, it must be stressed that there are hardly any good field data available to support such a figure. For example, the OXFAM disaster sanitation unit, designed for a population of 500 and provided with twenty squatting plates, is able to serve a population of 1,000 to 1,500 (i.e., fifty to seventy-five users per squatting plate or two to three times the design figure) in the "bustee" areas of urban Bangladesh. Yet, how well it serves that number of people--in the sense of the time spent in queuing, especially at "peak" periods--has not been reported.

The toilet compartments should be arranged in separate blocks for men and women. Urinals should be provided in the men's block and the total number of urinals and compartments in the men's block should be the same as the number of compartments in the women's.

Location

In high density areas (over 1,000 people per hectare), the number of people that can be served by one communal sanitation block (usually 200 to 500 people) will normally determine the required number and location of communal facilities, rather than the distance people can be expected to walk to them. For example, if the population density is such that only one communal block is required per hectare, then the maximum distance that people would be required to walk is around 100 meters, which is a 1.2 minute walk at a speed of 5 kilometers per hour.

Toilet type

The ideal type of toilet for installation in a communal sanitation facility is a PF or low-volume cistern-flush toilet. Water use may amount to 15-20 liters per capita daily.

Shower and laundry facilities

If shower and clothes washing facilities are not available in individual households, these should be provided at the communal sanitation blocks (for approximately one to fifty people in warm climates); the water requirement for showering is 15 to 25 liters per capita daily. Additionally, handbasins should be provided at the rate of one for ten people; water use may be estimated as 5 to 15 liters per capita daily. Both shower and handbasin water use may be considerably reduced by the provision of water-saving plumbing fixtures. In warm climates it is usually not necessary to provide hot water since the cold water storage tank will normally contain water warm enough for personal washing.

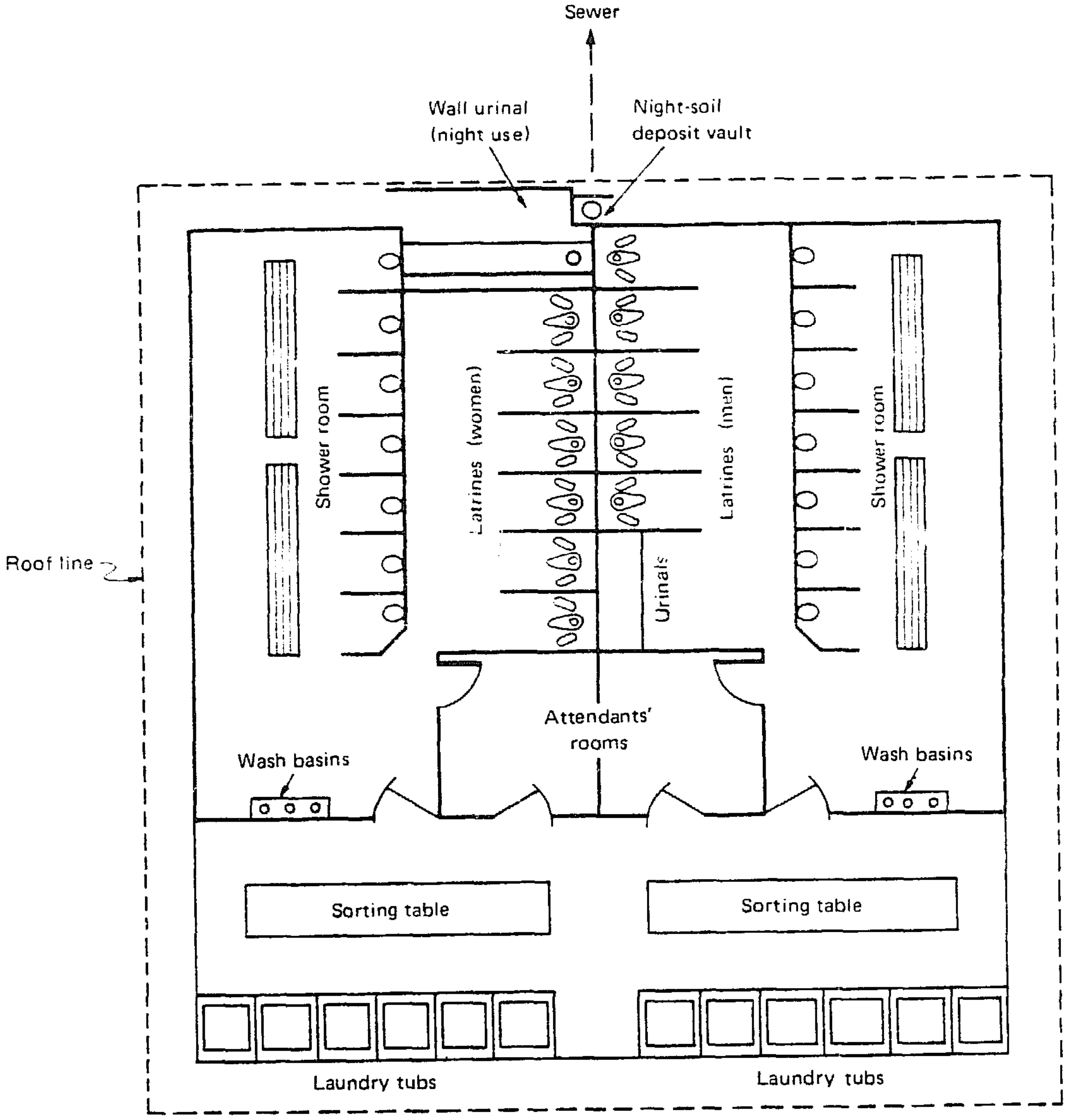
It may also be necessary to provide laundry facilities. The exact style of these facilities should conform to local preference. Approximately one washing tub should be provided for fifty people. Clothes drying lines may be required.

In communal facilities with compartments reserved for the exclusive use of one household, each compartment may contain a shower and handbasin in addition to the toilet if sufficient space is available. Whether it is necessary to provide a private laundry tub as well, rather than communal laundry facilities, is a decision best taken after discussion with the community.

Effluent disposal

Generally a low-cost sewerage system should be used but soakage pits for PF toilets and sullage water disposal to stormdrains have also been used successfully. If the toilets are of the cistern-flush type, a septic tank should be provided so that the sewers can be of small diameter and laid at flat gradients. The septic tank should follow the design described for sewered PF toilets in chapter 8, section 5. If the toilets are aquaprivies, a settlement tank is already included in the design and provision needs to be made for only a small tank to settle sullage. If the terrain is such that velocities of 1 meter per second can be obtained in the sewer without the need for excessive excavation or pumping, the sewerage system can be of the conventional kind and the septic tank would no longer be necessary. In areas where communal sanitation blocks can be installed near a trunk sewer serving other parts of the town, they should of course be connected to it.

Figure 9-4. Schematic of a Communal Sanitation Facility



CHAPTER 10

TREATMENT AND DISPOSAL OF SULLAGE

The adoption of on-site excreta disposal technologies such as improved pit latrines, compost toilets, and PF latrines with soakpits or vaults (but excluding septic tanks) requires that separate facilities be provided for sullage disposal. Sullage is defined here as all domestic wastewater other than toilet wastes; it is thus the wastewater from showers and sinks and includes laundry and kitchen wastes as well as water used for personal washing. It contains some excreted pathogens; per capita contributions of enteric indicator bacteria in sullage are generally 10^4 to 10^5 lower than those in sewage. Sullage also contains a variety of organic compounds, most of which are readily biodegradable (with the notable exception of "hard" detergents if these are present in locally manufactured washing powders). Approximately 40 to 60 percent of the total houshold production of waste organics (excluding garbage) is associated with sullage--that is, some 20 to 30 grams BOD per capita daily. This figure, however, depends on water consumption; a family with suitable facilities and abundant water for personal dish and clothes washing will obviously generate more sullage BOD than one that obtains only small quantities of water for drinking and cooking purposes from a public standpipe and uses stream water and for washing clothes or sand to clean cooking utensils.

The volume of sullage generated is clearly related to water consumption. In many industrialized countries sullage accounts for 50 to 70 percent of total domestic water use, the balance being used to flush cistern-flush toilets. A similar situation exists in the more affluent communities in developing countries, and it is assumed that in communities that have a water consumption of 200 to 300 liters per capita daily and cistern-flush toilets the volume of sullage generated is approximately 60 percent of the water consumption (excluding garden watering). With other (less affluent) urban communities in developing countries, the prediction of sullage volumes is more difficult. Tentative estimates, however, are as follows:

(1) In households with a hand-carried water supply (obtained from public standposts or vendors) and pit latrines or compost toilets, sullage generation may be conservatively estimated as the water consumption; that is, normally around 20 to 30 liters per capita daily less any amount used for PF toilets.

(2) In households with an on-site single-tap water supply and PF toilets or vaults, the sullage volume can be taken as the water consumption (excluding that used for garden watering and the 3 to 6 liters per capita daily flushwater); that is, normally about 50 to 100 liters per capita daily.

Local water use figures should of course be used wherever possible. They are seldom difficult to obtain, even by actual measurement in the field.

In contrast it is very time consuming to obtain good estimates of the daily per capita BOD contribution in sullage. No data on this are available for urban areas in developing countries, but it is probably reasonable to estimate that the BOD_5 of sullage is around 100 to 350 milligrams per liter.

In developing countries sullage is therefore a wastewater with as much BOD_5 as raw sewage in North America. Indeed there are many canals and streams in urban areas of developing countries that are grossly polluted (BOD_5 up to 250 miligrams per liter) by sullage and garbage. Indiscriminate sullage disposal may not only damage the environment but also may have serious public health consequences.

There are basically four kinds of sullage disposal systems:

(1) disposal by tipping in the street, house yard, or garden;

(2) on-site disposal in soakaways;

(3) disposal in open drains (commonly stormwater drains); and

(4) disposal in covered drains or sewers.

Each system has different health risks and these are reviewed below preceding the discussion of design considerations.

Health Aspects

Tipping sullage on the ground in backyards or gardens may create breeding sites for either anopheline or culicine mosquitoes, including *Culex pipiens*, which is a cosmopolitan nuisance and a potential vector of bancroftian filariasis in some areas of the world and one reported to prefer slightly polluted water. It may also create muddy and unsanitary conditions that could help to promote the development of helminth ova, which require a fairly moist environment. In a clean dry yard, ova in children's feces are unlikely to develop. A wet muddy yard, however, will conceal any feces deposited and will promote development of worm eggs and larvae. There is evidence that families whose yards are clean and dry (due to hygienic practices and/or soil types) have lower intensities of *Ascaris* infection than do other families. Sullage containing pathogens from bathwater may infect children playing in the yard. In permeable soils or where evaporation is high, and where sullage production and housing density are low, tipping of sullage onto the ground is unlikely to give rise to a significant health hazard. Where the soil is less permeable, evaporation is low, and land slopes permit ponding, a separate system for sullage disposal becomes necessary. Similarly, where either water use or housing density is high, an alternative method of sullage disposal becomes essential.

Sullage disposal in properly designed and constructed ground seepage pits causes only a low risk of groundwater contamination, because the risk of microbiological and nitrate pollution of groundwater from sullage is very much lower than it is with sewage, since sullage contains far fewer pathogens and much less nitrogen.

Sullage disposal in open drains, such as stormwater drains, provides the most readily identifiable potential health risk--namely that of promoting the breeding of mosquitoes. In areas of year-round rainfall, these drains will contain water continuously, and if they are kept free of garbage and are well designed they will flow freely and provide few sites for mosquito breeding. The presence or absence of sullage will therefore make no difference. In areas of seasonal rainfall, however, especially where the drains are liable to become blocked with garbage or trash during low rainfall months, the addition of sullage will create year-round water and thus year-round mosquito breeding where previously only seasonal breeding may have occurred. Here it is not the quality of the sullage that is important, since ponded stormwater would also be sufficiently polluted to allow Culex pipiens breeding, but it is rather the continuous production of sullage that may have the effect of converting wet season breeding into year-round breeding in areas where the stormwater drains are liable to pond. The change from wet season breeding to year-round breeding seems likely to lead to an increase in filariasis transmission, prevalence, and intensity, although no field data has been found to confirm this hypothesis.

Sullage disposal in closed drains or sewers is expensive, but has no special health problems unless it is eventually discharged without treatment into a sluggish or intermittent stream where it may promote Culex breeding. The disposal of sullage, along with excreta, into sanitary sewers also presents no additional health risks, but this is in itself no justification for the provision of conventional sanitary sewers.

Engineering Design

Seepage pits

A suitable design for a seepage pit for use in permeable soils is shown in Figure 8-25. The pit may be circular, square, rectangular, or even irregular in plan, to suit the space available. The side walls may be lined with open brickwork, or unlined and filled with rock (50- to 100-millimeter grading) or broken bricks. The rate of infiltration of sullage is approximately three times higher than that of conventional septic tank effluent; that is, approximately 30 to 90 liters per square meter of side wall area daily. For the purposes of design, 30 liters per square meter should be used, unless a higher rate is known to be more appropriate.

Stormwater drains

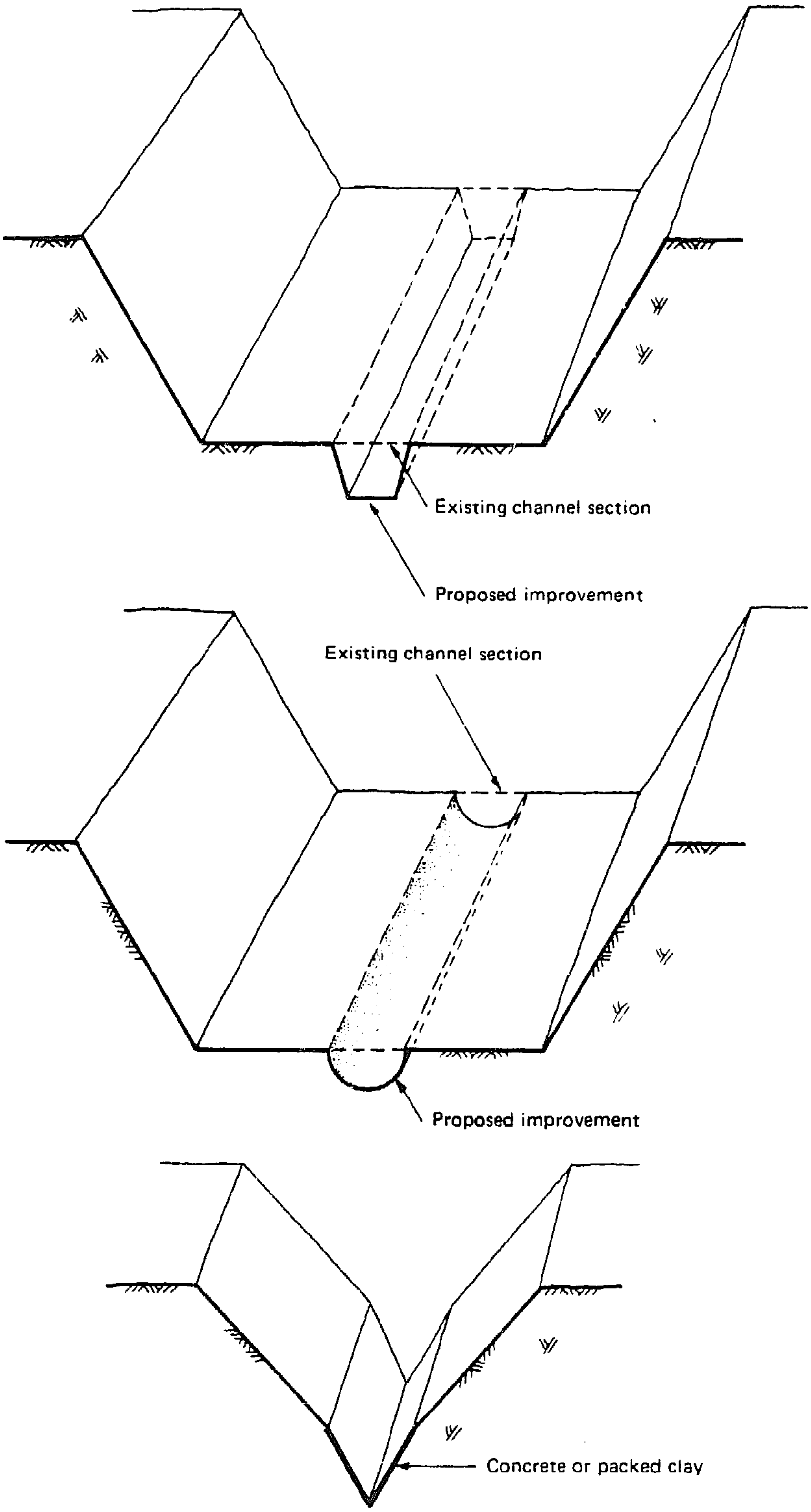
If stormwater drains are used for sullage disposal they must be designed so that they can handle low sullage flows, as well as flood peaks, without nuisance. Storm drains are normally designed with an approximately trapezoidal cross-section with a fairly wide base. This means that the depth and velocity of flow of the relatively small amounts of sullage (relative, that is, to the drain's stormwater capacity) will be low, and the risk of blockage and ponding high. If the storm drains are already in existence and lined, it is advisable (but somewhat costly) to modify the channel section by placing a small horizontal or semicircular channel along the invert where the sullage can flow with a higher velocity in the central section only. If the drains are not already lined, it would be advisable to pave the invert to provide a similar channel. If surface drainage is to be provided at the same time as the improvements in excreta and sullage disposal, it may be advisable to consider alternative channel sections such as triangular ones; apex lining would provide higher sullage velocities and minimize erosion and blockage but is probably too costly for routine application (see Figure 10-1.)

Whatever channel section is adopted, it is necessary to maintain the drains routinely. This includes removal of blockages and perhaps flushing with surface water. The maintenance can be done by municipal workers, by contracting the work to the private sector, or by motivating and organizing community effort on a neighborhood basis. The material removed from the drains should be disposed of in a sanitary landfill.

Sullage treatment

As noted above sullage has a reasonably high BOD, and large volumes of sullage may require treatment prior to discharge into local streams or rivers, unless their flow is such that the sullage would cause little additional pollution. If stormwater drains are used for sullage collection, these should discharge into a single facultative waste stabilization pond, which is normally the most convenient method of treatment wherever land is available. Maturation ponds are not necessary as the concentration of excreted pathogens in sullage is small. The pond should be protected from high stormwater flows in the wet season by incorporating a simple stormwater overflow weir at the pond inlet structure. For a detailed discussion of pond design criteria, see chapter 11.

Figure 10–1. Improved Stormwater Channels for Drainage of Sullage



CHAPTER 11

OFF-SITE TREATMENT

The degree to which excreta and sewage are treated is largely influenced by what is to be done with the resulting solid and liquid products. Minimum treatment is required for small flows discharged to the sea; maximum treatment is needed for effluents used for irrigation.

In general the treatment of human wastes in developing countries has two principal objectives:

(1) the removal or destruction of excreted pathogens, and

(2) the oxidation of organic matter.

The first objective is required to protect public health and the second to prevent pollution in the watercourse receiving the effluent. In communities where the incidence and prevalence of excreta-related infections are high and where the density of excreted pathogens in human wastes is therefore also high, the first objective is the more important. It is usually achieved by providing a suitable combination of time and temperature in the treatment works (Figure 9-1). It is fortuitous that the commonly selected combinations of time and temperature for pathogen removal enable the second objective to be achieved as well.

In this chapter emphasis is placed on the effectiveness of simple, low-cost processes in achieving low rates of pathogen survival. A brief discussion of conventional sewage treatment processes, which are not only more expensive but, without disinfection of the effluent, not very effective in pathogen removal, is given in chapter 9, section 1. Design examples of treatment processes discussed below are shown in the appendix to this chapter. Layout and design details are shown in Figures 11-1 to 11-4.

Waste Stabilization Ponds

Waste stabilization ponds are large, shallow ponds in which organic wastes are decomposed by microorganisms in a combination of natural processes involving both bacteria and algae. Stabilization pond systems can treat raw sewage, the effluent from sewered PF toilets, diluted night soil, or sullage.

Waste stabilization ponds are the most economical method of sewage treatment wherever land is available at relatively low cost. Their principal advantages in developing countries are that they remove excreted pathogens at a much lower cost than any other form of treatment and that they have minimum operating and maintenance requirements. In fact a pond system can achieve the total removal from the effluent of all excreted pathogens. This is not normally done because the possible additional benefits resulting from achieving zero survival, rather than very low survival, commonly are less than the associated incremental costs.

There are three types of ponds in common use:

(1) anaerobic pretreatment ponds, which function much like open septic tanks. They have retention times of 1 to 5 days and depths of 2 to 4 meters. Anaerobic ponds require periodic desludging and, if not properly designed, may have strong odors.

(2) facultative ponds, in which the oxygen necessary for bio-oxidation of the organic material is supplied principally by photosynthetic algae that grow naturally and with great profusion in them. They have retention times of 5 to 30 days (sometimes more) and depths of 1 to 1.5 meters. The lower layers of these ponds are usually anaerobic.

(3) aerobic maturation ponds, which receive facultative pond effluent and are responsible for the quality of the final effluent. They have retention times of 5 to 10 days and depths of about 1 to 1.5 meters. Each pond in a series of ponds is generally designed to reduce the fecal coliform concentration by about an order of magnitude.

Anaerobic and facultative ponds are designed for BOD removal, whereas the function of maturation ponds is the destruction or removal of excreted pathogens. Thus these three types of ponds should normally be used in conjunction to form a series of ponds. A single facultative pond treating domestic wastes is unsatisfactory; good designs incorporate a facultative pond and two or more maturation ponds. For strong wastes (BOD_5 >400 milligrams per liter) the use of anaerobic ponds pretreatment units ahead of facultative ponds is often advantageous since they minimize the land requirements of the whole pond system.

Well-designed pond systems, incorporating a minimum of three ponds in series and having a minimum overall retention time of 20 days, produce an effluent that will either be completely pathogen free or will contain only small numbers of enteric bacteria and viruses. Pathogenic helminths and protozoa will be completely eliminated. Any bacterial or viral pollution can be reduced or eliminated by adding more ponds to the system. The effluent is suitable for direct reuse or discharge into receiving waters.

Snail and mosquito breeding in properly maintained waste stabilization ponds does not occur. It is associated only with poor maintenance, which allows vegetation to emerge from the pond bottom or to grow down the embankment into the pond, thereby providing shaded breeding sites. This can be prevented by providing pond depths of at least 1 meter and concrete slabs or stone riprap at top water level. The latter strategy also prevents erosion of the embankment by wave action.

Proper and regular maintenance of ponds is simple but nonetheless essential. It consists merely of cutting the grass on the embankments and removing floating scum mats from the pond surfaces.

Night-soil Treatment Ponds

There is little experience with pond systems that treat night soil, but there is no evidence to suggest that the design and operation of night-soil ponds is different from ponds treating strong agricultural wastes or, indeed, domestic sewage. Since night-soil ponds are not discussed in standard sanitary engineering texts, a typical design example is presented in the appendix to this chapter. The design criteria adopted are conservative, and it is anticipated that, as more field data on night-soil ponds become available, they may be considerably refined.

Night soil is taken here to mean the material removed from vault toilets. This may be more dilute than the contents of bucket latrines. In areas where PF latrines are used, the vaults will contain 3 to 6 liters per capita daily of PF water. Assume that the average adult produces 250 grams (wet weight) of excreta with a moisture content of 80 percent and 1.2 liter of urine with a total BOD_5 of 21 grams. The vault contents will thus have a solid concentration of 0.7 to 1.1 percent and BOD_5 of 2800 to 4800 milligrams per liter, depending on the amount of PF water. If additional water is used for anal cleansing, these figures will decrease slightly, and if paper is used they will be higher. Thus night soil from vault toilets is a dilute slurry with a reasonably high BOD; it is often thought to be similar to primary sewage sludge, but it contains higher pH (usually >8) and about 60 percent of its solids are present in true solution.

Thermophilic Composting

Another suitable treatment method is thermophilic composting. Before vault night soil, septic tank sludge, or raw or digested sludge can be composted, however, its moisture content must be reduced to below 60 percent. Mechanical dewatering, although simple enough in theory, is not considered appropriate since it is in practice a complex process with many snags. Experience in Europe and North America with conventional sludge dewatering, especially at smaller works, has not been very encouraging, and there is no reason to suppose that night-soil dewatering is likely to be more successful in developing countries. Mechanical dewatering of any type requires a reliable and continuous supply of chemicals and energy. In addition, the liquor removed from the dewatered sludge contains high concentrations of both BOD and excreted pathogens and requires treatment in aerobic waste stabilization ponds.

In contrast, moisture control of vault night soil is more simply achieved, and at lower cost, by mixing it with moisture-absorbing, biodegradable waste materials such as sawdust, wood chips, rice husks, cotton gin trash, straw leaves, or previously composted night soil. Sufficient materials should be added to reduce the moisture to below 60 percent; the precise quantities required must be determined by experiment. The same materials will raise the carbon:nitrogen ratio from about 10:1 in the night soil to the 20 or 30:1 needed for preventing loss of ammonia and for optimum composting. Note that previously composted material can be recycled and used as the moisture-absorbing material.

Night soil with moisture levels below 60 percent may be composted in windrows in the open air for a period of 2 to 3 months. Windrows are long mounds of the composting material, usually approximating a trapezoidal cross-section; typical dimensions are: base width, 1.5 to 2.0 meters; top width, 0.75 to 1.0 meter; and height, 1.5 to 2.5 meters. Aerobic conditions within the windrow may be maintained by turning over the windrow contents daily at first, decreasing to 3- to 5-day intervals by the end of a 3- to 5-week composting period; essentially this entails building a second windrow from the contents of the first. This also ensures that all the material is exposed to the high temperatures (55 to 65°C) generated within the windrow by thermophilic bacterial activity.

High-rate composting can be achieved by forced draft ventilation of the windrows with air blowers. Alternative applications of this process, known as the BARC [1] aerated pile composting system, are shown diagrammatically in Figure 11-5. Further details of the process are given in the appendix to this chapter. Essentially the process consists of the maintenance of highly aerobic conditions in the windrow by drawing air in through the windrow surface and exhausting it from the bottom through a series of perforated pipes and a 1/3-horsepower blower. Very high temperatures (>80°C) have been achieved using this process, even during wet weather and when the ambient temperature was below 0°C. Pathogen destruction is complete within a few days, but the process is continued for up to 30 days in order to produce a more stable compost. Odors are eliminated by passing the exhaust air through a filtering pile of compost. The BARC process is inexpensive: estimated total annual per capita costs, based on United States experience, are $0.64 to $0.85 (1977 prices, for a plant treating 10 tons of dry night-soil solids per day). These costs can be reduced further if the compost is marketed. If there is no local use for the compost, the process should be stopped after 10 days and the pathogen-free product disposed of on land.

There are many other technologies for aerobic composting of various combinations of night soil, sewage sludge, livestock manures, and refuse with high organic contents. Among these is the Dutch VAM system, in which unsorted municipal refuse is mechanically placed in large windrows into which air may

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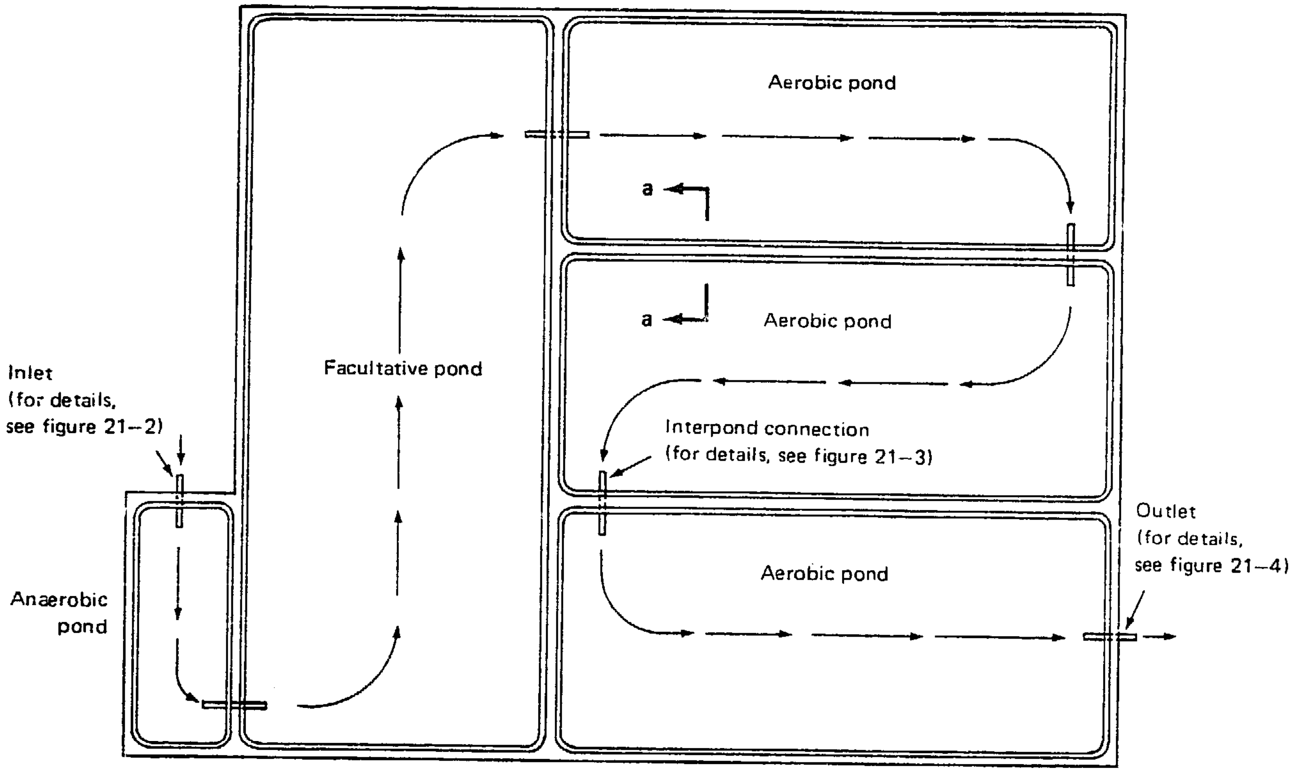
[1] The Beltsville Agricultural Research Center (BARC), located in Beltsville, Maryland, is a facility of the U.S. Department of Agriculture.

be forced from pipes lying underneath the pile (the opposite of the BARC system). Other systems include: rotating inclined cylinders, which tumble and aerate solid wastes for 6 to 8 days; closed bins/towers, built where space is restricted and in which air is forced through the composting wastes, such as the BIOREACTOR; and closed systems that can recycle a portion of the product for bulking and moisture control.

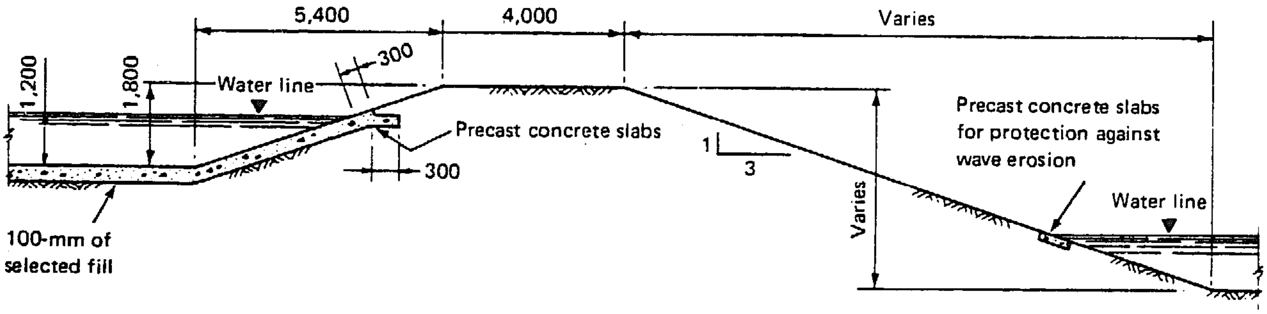
Some proprietary composting systems include "seeding" with expensive special cultures of microorganisms; these have been marketed from time to time for many years on the basis of promotional promises. They do neither harm nor good; the bacteria and other microflora needed for composting are already present in raw wastes in more than sufficient number to provide the seeding.

Information on composting presented in this chapter has been limited to the BARC process because it is simpler, less expensive, and less complicated than other aerobic systems and because it works. The alternative system, designed for limited space and based on similar principles, is the BIO-REACTOR. The most complete single source of information on the science and technology of composting is published serially by Kumpf, Maas, and Straub (1964-78). A current summary in which health aspects are stressed is found in Shuval, Gunnerson, and Julius (1980). A detailed description of the BARC system and its operation is contained in the appendix to this chapter.

Figure 11–1. Stabilization Pond Layout and Details (millimeters)



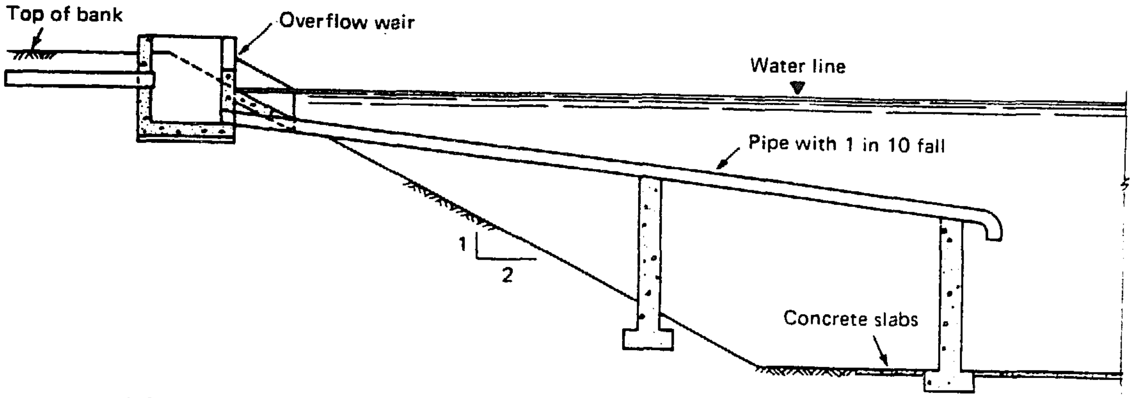
Plan layout
(not to scale)



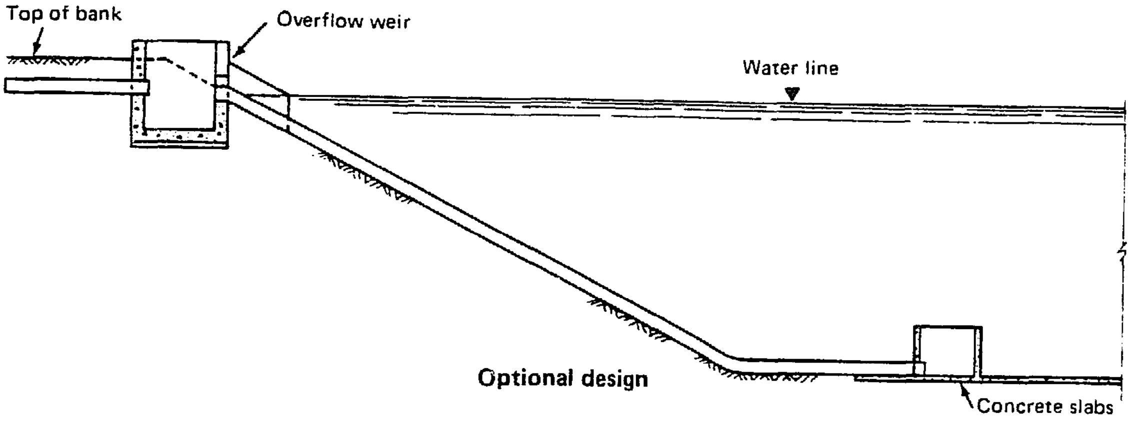
Section a-a

Detail of a typical embankment

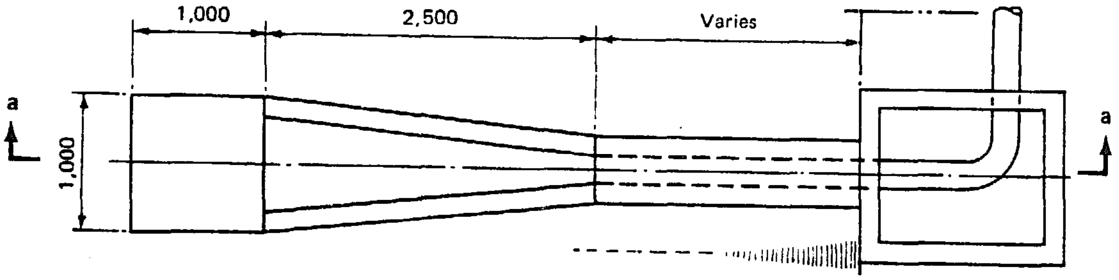
Figure 11–2. Inlet Structures for Stabilization Ponds (millimeters)



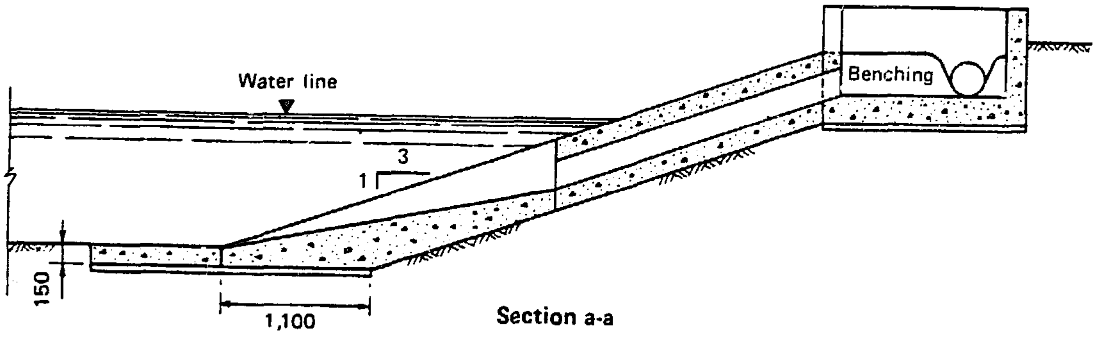
Inlet arrangment for a deep anaerobic lagoon (the pipe should discharge well away from the embankment to avoid the development of sludge banks)



Optional design



Plan

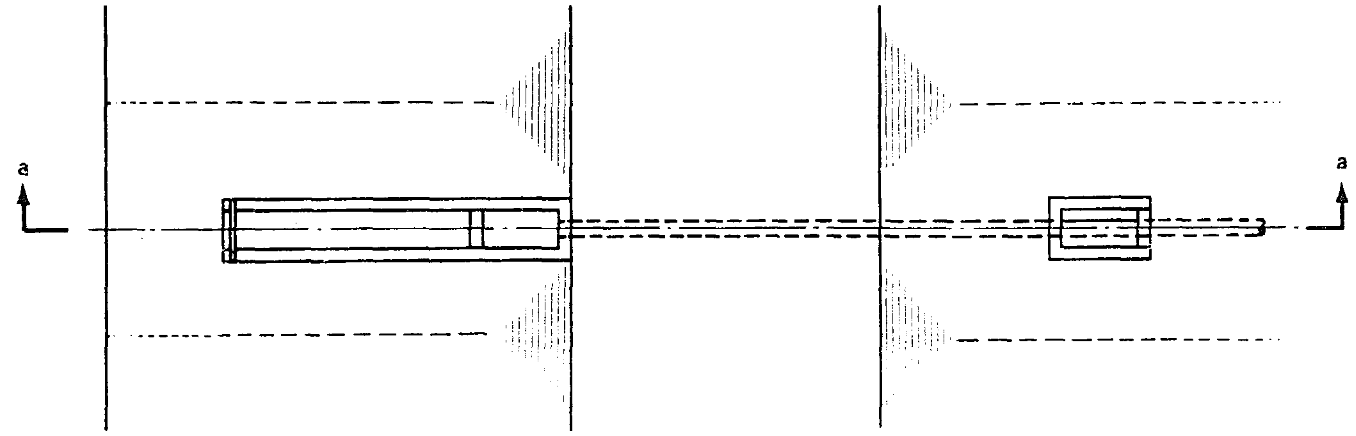


Section a-a

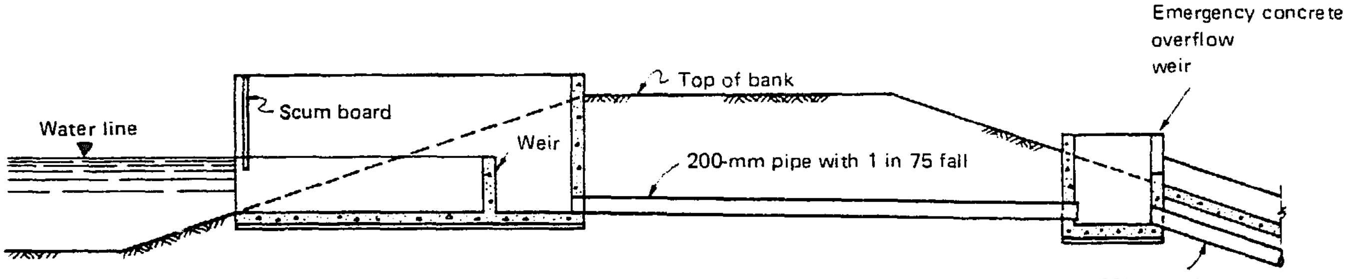
Inlet chute for a facultative or maturation lagoon

Source: Mara (1976 in bibliog.)

Figure 11–3. Alternative Interpond Connections (millimeters)

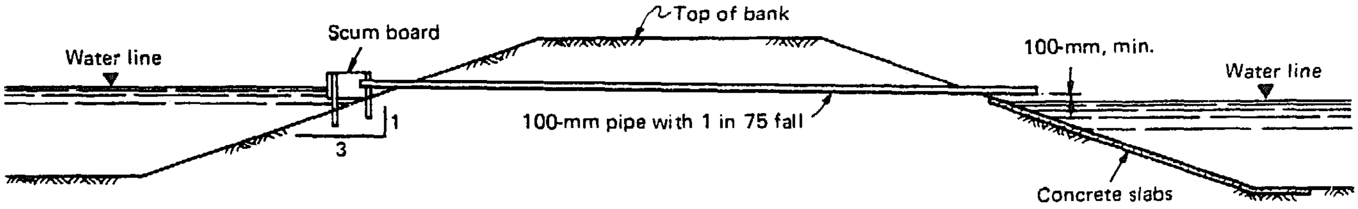


Plan



Section a-a

Interpond connection with concrete overflow weir

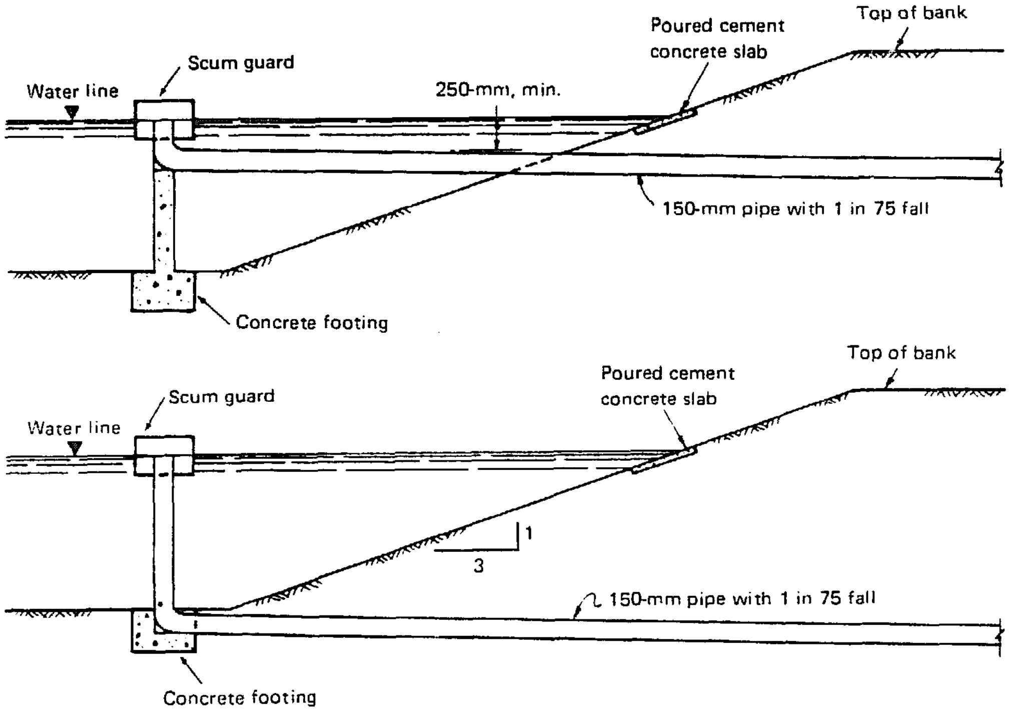


Simple interpond connection suitable for small lagoons

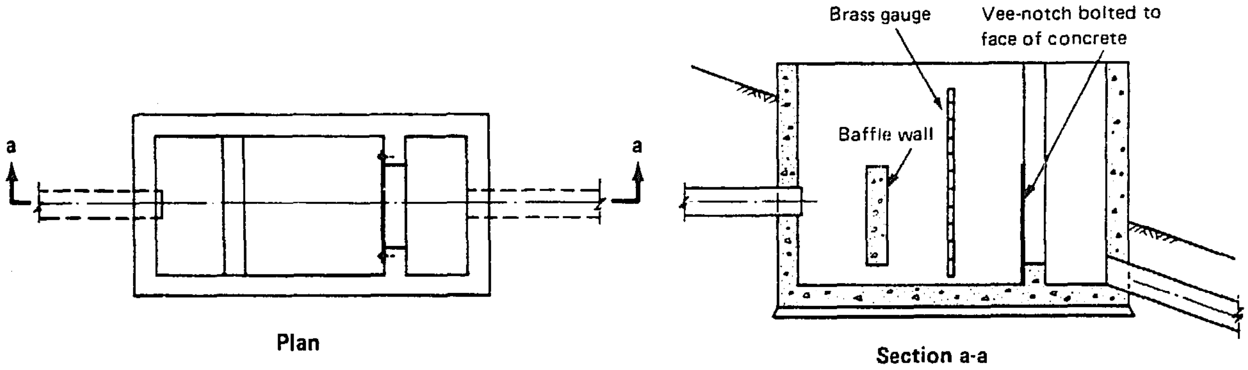
Note: Interpond connection comprising a concrete overflow weir and a downstream junction chamber would be connected to an inlet chute similar to that shown in figure 21–2.

Source: Mara (9176).

Figure 11 –4. Stabilization Pond Outlet Structures (millimeters)



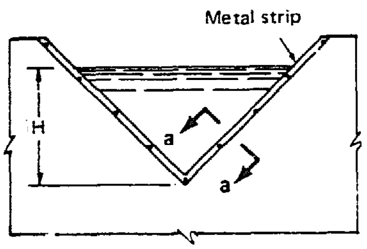
Alternative interpond connections made from standard pipe fittings



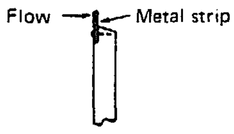
Plan

Section a-a

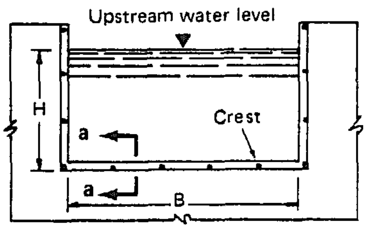
Flow-measuring chamber for final effluent.



90° triangular weir
(Q, m3/sec = 1.38 H5/2)



Edge of weir
(section a-a)

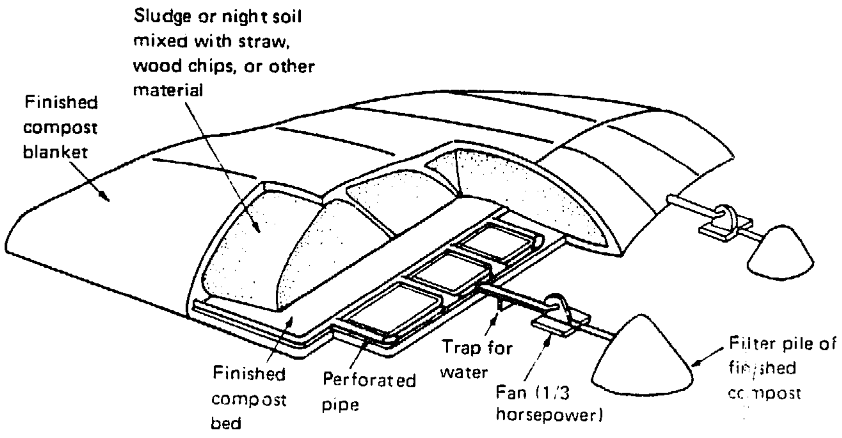


Rectangular weir
(Q, m3/sec = 1.84 BH3/2)

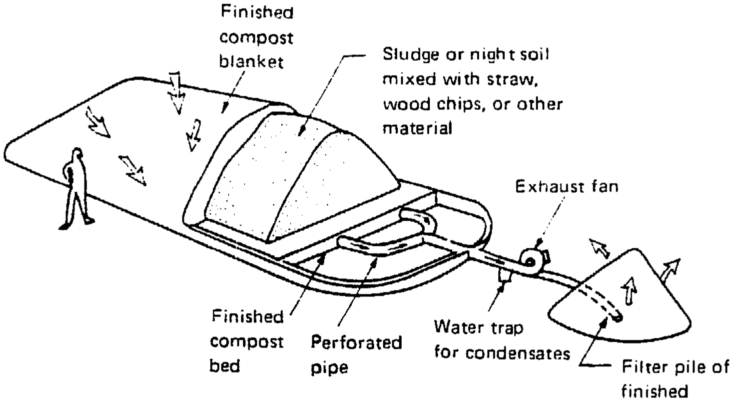
Note: Q, Quantity; m3/sec, cubic meter per second; H, height; B, breadth.

Sources: For flow-measuring chamber, Mara (1976); for weirs, Okun and Ponghis (1975).

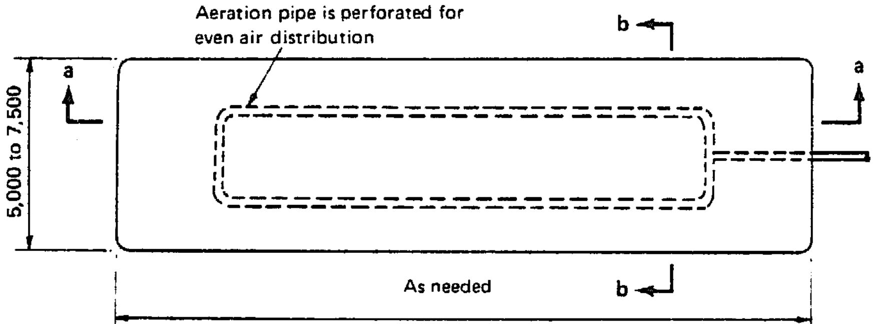
Figure 11–5. Beltsville Agricultural Research Center (BARC) System for High-rate Thermophilic Composting (millimeters)



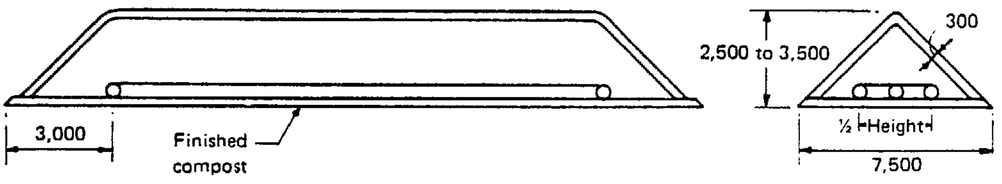
Composting extended piles with forced aeration



Composting with forced aeration



Plan

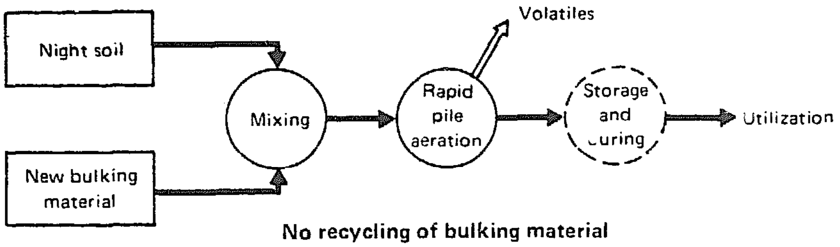


Section a-a

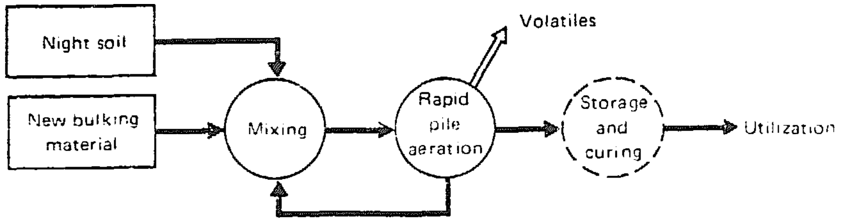
Section b-b

Schematic

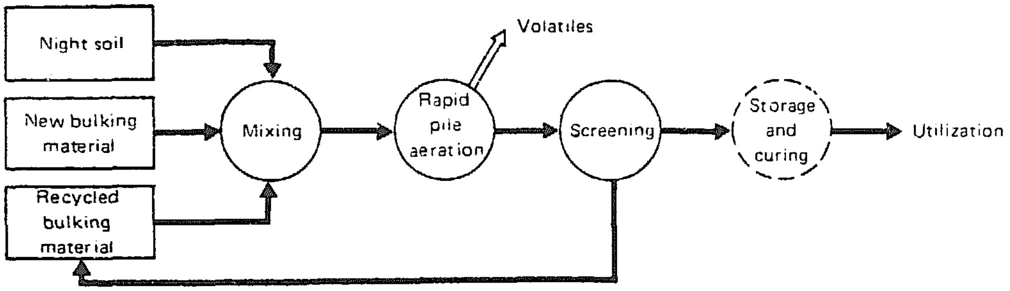
Figure 11–6. Alternative Flow Diagrams for Composting Night Soil by (BARC) System



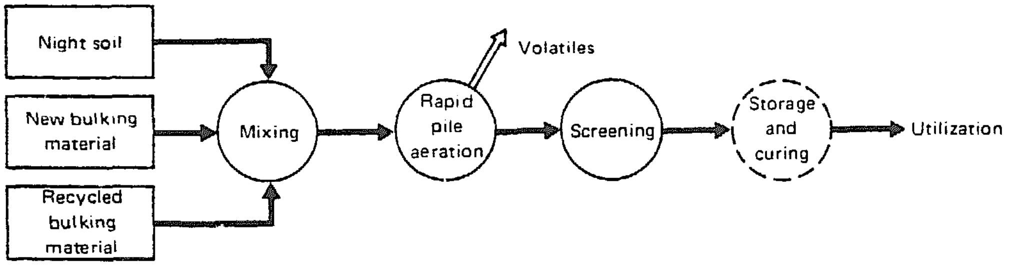
No recycling of bulking material



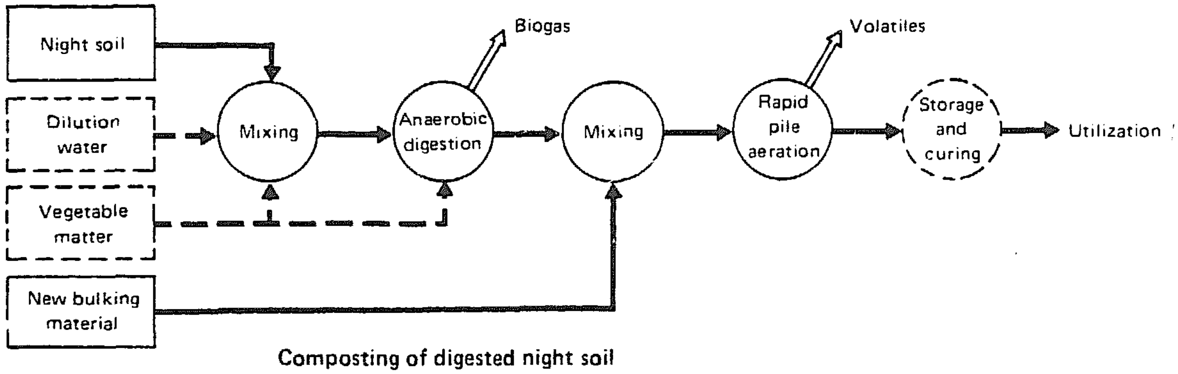
Partial recycling of unscreened compost



Recycling of bulking material



Recycling of bulking material and unscreened compost



Composting of digested night soil

APPENDIX

Waste Stabilization Ponds

Anaerobic Ponds

Design. The kinetics of BOD removal in anaerobic ponds is similar to that in conventional anaerobic digesters. In practice, lack of reliable field data has led to inherently conservative empirical designs based on the daily quantity of BOD_5 applied per unit volume:

$$\lambda_v = L_i \ Q/V, \qquad \text{(Eq. 1)}$$

where λv = volumetric BOD_5 loading, $g/m^3/d$;

L_i = influent BOD_5 concentration, mg/l;

Q = influent flow rate, m^3/d;

V = volume of pond, m^3.

Odor Release. Provided that the volumetric BOD_5 loading is below 400 g/m^3 daily and stable alkaline fermentation with methane evolution is established, minimal odor release occurs. If the wastewater is acid, the pH should be adjusted with lime soda ash to a pH between 7 and 8.

Desludging. Anaerobic ponds should be desludged when they become half full of sludge. A sludge accumulation rate of 0.04 m^3 per person yearly is generally observed at temperatures above 15°C.

Facultative Ponds

Design. There are a number of design procedures for facultative ponds, which generally have a depth between 1 and 2 meters. The one described here is based on the areal BOD_5 loading, λ_s ; this parameter is the daily quantity of BOD_5 applied to the pond per unit surface area:

$$\lambda_s = 10 \ L_i \ Q/A, \qquad \text{(Eq. 2)}$$

where λ_s = areal BOD_5 loading, kg/ha/day,

A = pond area, m^2,

and L_i and Q are as defined above.

The maximum value of λ_s that can be used for design is a function of temperature from an analysis of performance data of facultative ponds obtained worldwide. It is recommended that design be based on the relationship:

$$\lambda_s = 20T - 120, \qquad \text{(Eq. 3)}$$

where T = mean temperature of the coldest month, °C. (This formula works well in areas having a temperature range of 15°C and up.) Thus, the pond area is given by:

$$A = \frac{L_i\, Q}{2\,(T - 6)}. \qquad \text{(Eq. 4)}$$

BOD5 removal in facultative ponds is a function of the loading. McGarry and Pescod (1970) found the following relationship in Eq. 5, where λ_r is the kg/ha/day of BOD5 removed:

$$\lambda_r = 0.725\, \lambda_s + 10.75. \qquad \text{(Eq. 5)}$$

Percentage BOD5 removal is generally from 70 to 85 percent. An effluent BOD5 over 100 mg/l indicates a predominantly anaerobic pond; 40 to 80 mg/l indicates a predominantly aerobic one. Additional removals are achieved in maturation ponds.

Desludging. In facultative ponds that treat raw or screened sewage, a sludge layer forms on the pond bottom. Approximately 30 percent of the influent BOD5 is removed as methane from the sludge layer. Facultative ponds should be desludged when they are a quarter full of sludge and, as with anaerobic ponds, a sludge accumulation rate of 0.04 m^3 per person yearly may be predicted (assuming that suitable traps are provided to remove grit, sand, or ash residues that may be in the incoming sewage). Facultative ponds that receive the effluent from anaerobic ponds (or sewered PF toilets) do not normally require desludging.

Maturation Ponds

Design. Maturation ponds are usually designed on the basis of fecal coliform removal rather than BOD removal. The model most commonly used in design for the removal of fecal coliforms in waste stabilization ponds is first-order kinetics in a completely mixed reactor. The kinetic equation is:

$$N_e = \frac{N_i}{1 + K_{b(T)}\, t^*}, \qquad \text{(Eq. 6)}$$

where N_e = number of fecal coliforms per 100 ml of effluent,

N_i = number of fecal coliforms per 100 ml of influent,

$K_{b(T)}$ = first-order rate constant for fecal coliform removal at $T^{o}C$, day^{-1},

t^{*} = mean hydraulic retention time, days.

The rate constant varies with temperature according to the equation:

$$K_{b(T)} = 2.6\ (1.19)^{T-20}. \qquad \text{(Eq. 7)}$$

In a series of anaerobic, facultative, and maturation ponds, equation 6 is written as:

$$N_e = \frac{N_i}{(1 + K_{b(T)}\ t^{*}_{an})\ (1 + K_{b(T)}\ t^{*}_{fac})\ (1 + K_{b(T)}\ t^{*}_{mat})^{n}}, \qquad \text{(Eq. 8)}$$

where t^{*}_{an}, t_{fac}, and t_{mat} are the retention time in the anaerobic, facultative, and maturation ponds, respectively, and n is the number of maturation ponds (which ideally are all the same size); N_i and N_e refer to the fecal coliform concentrations in the raw sewage and the final effluent, respectively.

Retention times in maturation ponds are usually in the range of 5 to 10 days and the number of maturation ponds required depends on the desired values of N_e. A representative design value of N is 1 x 10^{8} per 100 ml. Note that two maturation ponds, each with 5 to 10 days retention, will normally reduce the BOD_5 of facultative pond effluent from about 60 to 100 mg/l to below 30 mg/l.

Physical Design of Ponds

Generally rectangular ponds with length to breadth ratios of 2 or 3 to 1 and embankment slopes of 1 in 3 are used wherever possible. The embankment is protected from erosion by wave action by placing precast concrete slabs or stone riprap at surface water level.

The pond base should be impermeable. In coarse permeable soils the pond base should be sealed with plastic sheeting or clay.

The inlet and outlet structures should be as simple as possible; a wide variety of low-cost designs is available. For all ponds, V-notch weirs, rectangular weirs, or, if necessary, Parshall flumes may be installed to measure influent and effluent flows as required for performance evaluation.

Typical layouts and details are shown in Figures 11-1 through 4.

Design Example

Assume a population (P) of 100,000, a BOD_5 contribution of 40 gcd, and a wastewater flow of 80 lcd. The design temperature is 20°C. The design concentration of fecal coliforms in the final effluent is to be 100 per 100 ml. The sewage is to be treated by anaerobic, facultative, and maturation ponds operating in series.

(1) Anaerobic pond

Flow, $Q = 80 \times 10^{-3} \times 100{,}000 = 8{,}000\ m^3/day$.

Influent BOD_5, $L_i = 40 \times 10^3/80 = 500\ mg/l$.

Taking λ_v as 250 $g/m^3/day$, the volume (V) is given by:

$$\begin{aligned} V &= L\ Q/\lambda_v \\ &= 500 \times 8000/250 = 16{,}000\ m^3. \end{aligned}$$

If the depth is 3 m, the area would be 0.53 ha. The hydraulic retention time (= V/Q) is 2 days, so that the BOD_5 removal would be around 60 percent. Desludging would be required every n years, where n is given by:

$$\begin{aligned} n &= \frac{V/2}{P \times 0.04} \\ &= \frac{16{,}000/2}{100{,}000 \times 0.04} = 2. \end{aligned}$$

This assumes a sludge accumulation rate of 0.04 m^3 per person yearly and that the pond is desludged when it is half full of sludge.

(2) Facultative Ponds

From equation 4 the area (A) is given by:

$$\begin{aligned} A &= \frac{L_i Q}{2T - 12} \\ &= \frac{(500 \times 0.4) \times 8000}{(2 \times 20) - 12} = 57{,}000\ m^2 \text{ or } 5.7\ ha. \end{aligned}$$

If the depth is 1.5 m, the volume would be 86,000 m^3 and the retention time 11 days. Assuming a conservative BOD removal of 70 percent, the effluent BOD_5 would be 60 mg/l.

(3) Maturation Ponds

For $N_e < 100$ per 100 ml, try three maturation ponds, each with a retention time of 5 days:

$$N_e = \frac{N_i}{(1 + K_{b(T)}\ t^*_{an})\ (1 + K_{b(T)}\ t^*_{fac})\ (1 + K_{b(T)}\ t^*_{mat})^3}$$

$$= \frac{10^8}{[1 + (2.6 \times 2)][1 + (2.6 \times 11)][1 + (2.6 \times 5)]^3}$$

$$= 200,$$

which is too high. Repeating the calculation, assuming three ponds with 6.5 days, retention, gives a value for N_e of 95, which is satisfactory. The area (A) of each pond, assuming a depth of 1.5 m, is given by:

$$A = Qt^*/D$$

$$= 8{,}000 \times 6.5/1.5 = 35{,}000\ m^2.$$

Thus the total working area of the pond system is approximately 17 ha. The total retention time is 32.5 days; since this is greater than 20 days, the effluent will be completely free of helminth eggs, larvae, and protozoan cysts. If the anaerobic pond were not included in the design, the required area would be 25 ha (for one facultative pond of 27 days' retention and four maturation ponds each of 5 days' retention).

-soil Treatment Ponds

Design Example

Assume a population of 100,000, a night-soil production of 8 lcd luding PF water), a night-soil BOD_5 of 5000 mg/l and a temperature of ,

The following equations are used for the design of anaerobic and ative ponds:

$\lambda_v = L_i Q/V,$ (Eq. 1)

$\lambda_s = 10 L_i Q/A,$ (Eq. 2)

$\lambda_s = 20T - 120,$ (Eq. 3)

λ_v = volumetric BOD_5 loading on anaerobic ponds, $g/m^3/d$;

λ_s = areal BOD_5 loading on facultative ponds, kg/ha/d;

L_i = influent BOD_5, mg/l.

Design computations are as follows:

(1) Anaerobic Pond:

Flow, $Q = (8 \times 10^{-3}\ m^3/\text{capita/day}) \times 100{,}000\ \text{capita} = 800\ m^3/d$.

BOD_5, L_i = 5000 mg/l.

Assume $\lambda_v = 250\ g/m^3/\text{day}$ as in previous example.

From equation 1:

$$V = L_i Q/\lambda_v = 5000 \times 800/250 = 16{,}000\ m^3.$$

For a depth, d, of 3 m, A = 0.53 ha.

Detention time = 20 days (assuming evaporation = precipitation),

Assuming 75 percent removal, the effluent BOD_5 = 1250 mg/l.

(2) Facultative ponds:

From equation 3, maximum BOD_5 loading,

$$\lambda_s = 20T - 120 = 20 \times 20 - 120 = 280 \text{ kg/ha/d}.$$

From equation 2, area (A) of pond:

$$A = \frac{10 \times (0.25 \times 5000 \text{ m/l}) \times 800 \text{ m}^3/\text{d}}{280 \text{ kg/ha/d}} = 35714 \text{ m}^2 = 3.57 \text{ ha}.$$

For d = 001.5 m, V = 53.6 m^3,
and detention time = 67 days.

Note that if daily evaporation equals or exceeds $\frac{800 \text{ m}^3/\text{d}}{3.57 \text{ ha}} = 22.4$ mm/d, there will be no outflow.

Assuming 80 percent removal, the effluent BOD_5 = 250 mg/l.

The minimum area of a second facultative pond is:

$$A = \frac{10 \times 250 \text{ mg/l} \times 800 \text{ m}^3/\text{d}}{280 \text{ kg/ha/d}} = 7{,}143 \text{ m}^2 = 0.7 \text{ ha}.$$

Assuming as above that evaporation = precipitation, the retention ime = 7143 m^2/800 m^3/d = 9 days

(3) Maturation Ponds:

A maturation pond with 5 days, detention would have a volume of 800 ^{3}/d x 5 d = 4000 m^3. For a depth of 1 m, the area equals 0.4 ha.

A total pond area of about 5 ha would thus be needed to treat the creta produced by a population of 100,000. If additional land is available, : is often more convenient not to have an anaerobic pond in order to avoid e need to desludge it every 2 years. In this case the facultative pond area) is given by equation 3 as:

$$A = 10\ L_i\ Q/\lambda_s,$$

$$= 10 \times 5000 \times 80/280 = 14{,}285 \text{ m}^2 = 14.3 \text{ ha}.$$

e retention time, assuming a depth of 2 m (to allow for additional sludge orage capacity), is 358 days -- nearly a year. Make-up water would be quired to maintain the depth when the daily evaporation exceeds 5.6 mm.

The kinetics of BOD removal in night-soil ponds have not been studied and so it is difficult to estimate with any precision the BOD_5 of the effluent. A conservative estimate, based on BOD removal in ponds treating domestic sewage, is that the effluent BOD_5 would be in the range of 40 to 100 mg/l. Further treatment in a small maturation pond with a retention time of 10 to 20 days might therefore be required if the effluent is to be discharged into a small watercourse. Since the facultative pond effluent would be completely free of excreted pathogens, however, further treatment would not be required if the effluent is to be reused in aquaculture or agriculture. Some caution is needed in the agricultural reuse of night-soil pond effluent since it may contain too high a concentration of dissolved salts, especially sodium. The available evidence is that chloride and sodium concentrations in night-soil pond effluents are in the range of 200 to 300 mg/l and 140 to 330 mg/l respectively, which compares well with concentrations of 100 to 660 mg/l and 60 to 360 mg/l respectively in effluents from ponds treating domestic sewage; but in areas where evaporation greatly exceeds precipitation, make-up water may be necessary to prevent build-up of salts to concentrations that inhibit algae growth.

Night-soil treatment ponds have two additional requirements over ponds treating sewage. First, there must be an adequate source of water locally available to replace evaporation losses. River water is normally suitable. Second, there must be unloading facilities for the night-soil tankers. The design should include a manually raked medium screen (e.g., 10-mm bars with 20-mm spacings), a night-soil pump with a capacity twice that of the largest night-soil tanker used, and a macerating pump that should discharge below the pond top water level and approximately 10 to 20 m away from the embankment. Provision should be made for the night soil to flow by gravity directly into the pond when the pump is under repair.

eltsville Aerated Pile Method Compost System (BARC) 1/

Flow diagrams presented in Figure 11-6 are based on mixing each olume of night soil or sludge with two volumes of woodchips, straw, rice ulls, groundnut hulls, leaves, or other carbonaceous bulking material that as a low moisture content of, say, 30 percent.2/ Finished composts can lso be used. During mixing, temporary odors are usually produced. Mixing an be done by turning with a Fresno scraper, roadgrader, front-end loader, r other machine. The final mix should be similar to a stiff concrete onsistency.

The purpose of the bulking material is to: (1) reduce the moisture ontent of the night soil to 40 to 60 percent; (2) provide structure or orosity for air movement through the mixture; and (3) provide carbon to aise the carbon to nitrogen (C:N) ratio to approximately 20 to 30 to 1. he C:N ratio of sewage sludge is in the range of 9 to 15 to 1. Raising the :N ratio reduces the loss of nitrogen as ammonia. The addition of carbon s a bulking material ensures the conversion of nitrogen into organic onstituents of the biomass.

The Aerated Pile

A three-dimensional schematic diagram of the Beltsville aerated ile method for composting night soil in sewage sludge is shown in Figure 11-6. n their simplest form the individual, stationary, aerated piles are contructed as follows:

(a) A loop of 4-inch (100-mm) diameter perforated plastic pipe is placed on the composting pad, and oriented lengthwise, directly under what will become the ridge of the pile. Perforated steel pipe can also be used and later removed for reuse. The perforated pipe should not extend under the end slopes of the pile because excessive amounts of air may be pulled through the sides, causing localized zones (i.e., "cold spots") that do not reach the thermophilic range. The pipe should be placed at least 2.5 to 3 m from the ends of the pile.

(b) A 15- to 20-mm layer of woodchips or other bulking material is placed over the pipe and the area to be occupied by the pile. This layer forms the pile base and facilitates the movement and distribution of air during composting. The base material also absorbs excess moisture that may condense and leach from the pile.

. Beltsville Agricultural Research Center (BARC), U.S. Department of griculture, Beltsville, Maryland.

. This material is taken largely from the appendix by E. Epstein in Shuval, unnerson, and Julius (1980).

(c) The mixture of sludge and woodchips is then placed loosely upon the prepared base (with a front-end loader or conveyor system) to form a pile, with a triangular cross-section, 5-m to 7.5-m wide and 2.5-m high (see Figure 11-5).

(d) The pile is completely covered with a 300-mm layer (often referred to as the "blanket") of cured, screened compost. The blanket layer provides insulation and prevents the escape of malodorous gases during composting. If finished compost is not available, as would be the case for the first piles of a new operation, the bulking material itself can be used for this purpose. The blanket thickness may have to be increased, however, to achieve the same degree of insulation and odor control as obtained with cured compost.

(e) During construction of the pile base, the perforated pipe is connected to a section of solid plastic pipe that extends beyond the pile base. The solid pipe is connected through a moisture trap with condensate drainage to a sewer or a soakaway and thence to a 1/3-horsepower blower controlled by a timer. Aerobic composting conditions are maintained by drawing air through the pile intermittently. The exact aeration schedule will depend on pile geometry and the amount of sludge to be composted. For a pile containing up to 80 tons of sludge (20 m x 5 m x 2.5 m), the timing sequence for the blower is 5 minutes on and 15 minutes off.

(f) The effluent air stream from the compost pile is conducted into a small cone-shaped pile of cured, screened compost approximately 1.2-m high and 2.5-m in diameter, where malodorous gases are effectively absorbed. These are commonly referred to as odor filter piles. The moisture content of compost used for this purpose will increase slowly. A 100-mm base layer of woodchips or other bulking material under the odor filter pile will minimize back pressures that could cause leakage of malodorous gases around the blower shaft. Research has shown that the odor filter pile should contain about 0.75 cubic meter of screened compost for each 10 wet tons (4 dry tons) of sludge being composted. In the case of new operations, where screened compost is not yet available, some bulking materials or soil (or a mixture thereof) could be used in the filter piles.

Variations in pile shape and size can adapt the process to differences in the rate of sludge production by most treatment plants. The individual pile method described here has been used for operations of from 5 to over 100 tons per week of sludge with 20 percent solids.

The Extended Aerated Pile

Another version of the aerated pile is the aerated extended pile. Each day's sludge production is mixed with a bulking material and a pile is constructed that utilizes the slope (lengthwise dimension) of the previous day's pile, thus forming a continuous or extended pile. The extended pile offers certain advantages for larger municipalities. For example, the area of the composting pad can be reduced by about 50 percent compared with that required to accomodate an equal amount of material in individual piles. Moreover, the amount of blanket material (i.e., screened compost) needed for insulation and odor control and the amount of bulking material for the pile base are both decreased by 50 percent.

In constructing an extended pile, the first day's sludge production is placed in an individual pile with triangular cross-section as described earlier. The exception is that only one side and the ends are blanketed. The remaining side is dusted with about 25 mm of screened compost for overnight odor control. On the next day, an additional aeration pipe is placed on the pad surface parallel to the dusted side, the pile base is extended, and the sludge-woodchip mixture is placed in such a manner as to form an extended pile. On the second day, the flat top and ends are blanketed with screened compost and the remaining side receives a thin layer of compost as before. The pile is extended each day for 28 days. After 21 days, however, the first day's section is removed for either drying and screening or placing in a curing pile. After the removal of seven sections in chronological sequence, there is sufficient space for operating the equipment so that a new extended pile can be started where the old one has been. Thereafter, a section is removed each day from the old pile and a section is added to the new one.

Temperatures Attained during Composting

The conversion of sludge into compost is essentially complete after 3 weeks in the aerated pile. Microbial decomposition of the volatile organic fraction of the sludge in an aerobic atmosphere soon raises the temperature throughout the pile to from 60° to 80°C, which effectively destroys pathogenic organisms that might cause diseases in human beings. Temperatures begin to decrease after about 16 to 18 days, indicating that the more decomposable organic constituents have been utilized by the microflora, stabilized, and transformed into compost. Studies in Maine and New Hampshire in the United States, and Ontario in Canada showed that neither cold weather nor snow affect composting.

Aeration and Oxygen Supply

Centrifugal fans with axial blades are usually the most efficient machines for developing the necessary vacuum to move air through the compost piles and into the odor filter piles. A pressure differential of about 125 mm (water gauge) across the fan has been adequate when woodchips are used as the bulking material. When finer textured materials such as sawdust are used, however, an increase in pressure differential will be required.

The aeration rate should maintain the oxygen level in the pile between 5 and 15 percent for rapid decomposition of the sludge and extended thermophilic activity. This level can be achieved with an aeration rate of about 14 m^3 per hour per dry ton of sludge. Research has shown that continuous aeration results in rather large temperature gradients within the pile. A more uniform temperature distribution is obtained by the use of intermittent aeration.

Four-inch (100-mm) flexible perforated plastic drainpipe has been used to collect the air under the piles and to deliver it to the odor filter piles. The pipe is damaged beyond reuse when the piles are taken down but, since it is relatively inexpensive, it is regarded as an expendable item. Rigid steel pipe has also been used and can be pulled lengthwise out of the pile without damage and reused. The pipe spacing for the extended piles should not exceed the pile height. The pipe should be large enough so that friction losses will not cause a pressure differential of more than 15 percent along the length of the perforated section. Manifolding the outer ends of the pipe will equalize pressure in the event of accidental damage to the pipe.

Condensate and Leachate Control

As air moves down through the composting sludge, it is warmed and picks up moisture. Temperatures near the base of the pile are slightly cooler as a result of heat loss to the ground. As the air reaches this area, it is cooled slightly, causing moisture to condense. When enough condensate collects, it will drain from the pile, leaching material from the sludge. Condensation will also collect in the aeration pipes and, if not vented, can accumulate and block the air flow. The combined leachates and condensate may amount to as much as 20 liters daily per ton of dry sludge. If the bulking material is sufficiently dry to begin with, there will be no leachate drainage from the pile. The leachate can be a source of odor if allowed to accumulate in puddles, so it should be collected and handled in the same manner as runoff water from the site.

The physical and chemical characteristics of the final product can affect the agronomic or utilization value of the compost. Particle size can affect application systems. Fine particles of material can be applied with standard fertilizer spreaders, whereas coarse particles may require special equipment. The chemical characteristics will affect the quantity and the way the material can be used. The C:N ratio of the compost used as fertilizer should not exceed 30:1, since this will require additional supplemental nitrogen. Woodchips and other high C:N ratio material therefore need to be screened out if the product is to be used as a low-analysis fertilizer. If refuse is used as a bulking material, screening is needed to remove undesirable material.

Curing and Storage

Compost should be cured for about 30 days (screened or unscreened). This may be done on the original pile with aeration turned off, or on a support pile. After airing, the compost may be used immediately or stored until demand for compost develops. Curing further stabilizes the compost. Use of the compost is ordinarily seasonal, with the bulk of it applied either at planting or harvest times. Thus, a curing and storage area is needed to accommodate 3 to 6 months' production.

During storage, the compost will continue to decompose at a slow rate. Even though compost is well stabilized, if it is stored in large piles at a moisture content above 40 percent, temperatures may increase to the thermophilic range, and additional composting will occur. This is no cause for concern, it may, in fact, actually improve the quality of the compost for some uses.

The compost can be stored without cover and may be piled as high as is convenient with the equipment available. Care should be taken to round the tops of the storage piles so that rain will run off and wet pockets do not develop.

Monitoring and Management

Monitoring is essential to ensure proper operating conditions, high temperatures for pathogen reduction, and odor control. Operational monitoring can be kept at a minimum with low-cost, unsophisticated equipment.

Temperatures will reveal more about the process than any other single parameter. Most of the pile should reach 55°C within 2 to 4 days, indicating satisfactory conditions with respect to moisture content, bulking material ratio, mixing, and pH.

Low average temperatures below 60°C can result from excessive aeration or too high a moisture content. The former can be corrected by reducing the blower cycle or placing a baffle in the pipe just in front of the blower. If the moisture content is too high it indicates an improper sludge-to-bulking material ratio in the mix. The pile can then be torn down and rebuilt with additional bulking material and future piles built with the correct ratio. Cold spots in the pile may also result from improper pipe spacing or an inadequate insulation cover. Temperature monitoring should be done daily for the first week. Once temperatures peak at the desired level, only periodic spot checks are needed. Bimetallic probe thermometers and mercury thermometers are both appropriate.

Odors

While night-soil sludge initially can emit a strong, unpleasant odor, it disappears quickly as the sludge is aerated. Each of the unit operations can be a potential source of odors. Some of the odors emitted are intermittent while others are continuous. Odor potential increases considerably during and immediately following periods of excessive precipitation.

To minimize the odor potential throughout the composting process, it is essential to manage each operation as follows:

a. The mixing operation. Prompt mixing of sludge and bulking material and placement of the mixture in the aerated pile reduces the time for odor generation.

b. Aerated pile surface. This will not be a source of strong odors if the blanket of compost is adequate for insulation. Thin spots or holes in the blanket will be a potential source of odors. The effectiveness of the blanket for odor control decreases when its moisture content exceeds 60 percent.

c. Air leakage between the blower and odor filter pile. Since air leakage can occur at this point, all joints should be sealed. Back pressure from the odor filter pile should be minimized to prevent gaseous losses around the blower shaft. Back pressure can be reduced by placing a 4- to 6-inch layer of bulking material under the filter pile; it will increase as the moisture content of the pile increases.

d. Odor filter piles, As mentioned earlier, the odor filter piles are a potential source of odors. They should be cone shaped, symmetrical, and contain about 0.75 m^3 of dry (50 percent moisture or less) screened compost per 10 wet tons of sludge being composted.

e. Condensate and leachate. These are potential sources of odors. As these liquids drain from the compost pile, they should be collected into a sump and piped to a soakaway or stabilization pond.

f. Removal of compost from the aerated pile to the curing pile. If the sludge has not been adequately stabilized prior to this operation, odors will be released. Excessive odor during this operation can probably be attributed to too high a moisture content in the composting mixture and can be avoided by lowering the moisture content of the mix with additional bulking material.

g. Curing pile. This can be a source of odors when the material removed from the aerated pile has not been completely stabilized. The use of drier materials in the initial mixing operation will prevent this problem. Blanketing the curing pile with dry cured compost will also help to contain any odors. Where night soils or sludges are incompletely composted after 21 days because of excess moisture, low temperatures, improperly constructed piles, or improperly treated sludge, the odor potential will be high. In these cases, the sludge should not be put on a regular curing pile, but mixed with additional bulking material and composted another 21 days, or put into a separate isolated pile, heavily blanketed with screened compost, and allowed to compost for several months.

h. Storage piles. Odors would arise only if the piles were constructed with excessively wet compost.

i. Aggregates or clumps of night soil or sludge. When aggregates of night soil or sludge are allowed to remain on the compost pad after mixing and processing, even though small in size, they can soon emit unpleasant odors. Workers should be made aware of this so that all aggregates of night soil or sludge are carefully removed from the mixing area as soon as possible.

j. Ponding of rainwater. When rainwater is allowed to pond on the site, anaerobic decomposition can occur and cause unpleasant odor. Therefore, the site must be graded and compost piles located so that ponding will not occur.

Site Design

The compost site should be located as close as possible to existing wastewater treatment or other waste disposal facilities. The advantages are: (1) low sludge hauling and transport costs; (2) use of existing institutions and infrastructure; and (3) combined composting of night soil, sewage, treatment sludge, and septic tank sludge.

Since night soil is collected in vacuum carts or trucks, the compost site can be located in nonresidential areas. The site should be located to provide easy access for transport and removal of the product. This may be adjacent to a rail line or barging facility on a river if the product is to be transported to remote agricultural areas.

Facilities design should take into consideration climate (especially precipitation and wind) and soil conditions. In areas where precipitation is high or distributed over the entire year, some cover may be needed for the various operations. These areas may also require a stable site underlain by concrete or asphalt. In addition, runoff facilities and drainage systems may be needed.

In dry or subhumid climates cover is not essential. Operations have been composting in the open without any problems. A stable base is recommended, however, where muddy conditions make it difficult to operate equipment and provide a potential for odors.

A sludge-composting facility should comprise the following areas: (a) receiving and mixing; (b) composting pad; (c) drying and screening; (d) compost, curing, and storage; (e) storage of bulking material; (f) administrative and maintenance building; and (g) runoff collection and disposal.

As indicated earlier, several of these areas may not be needed. The administrative, parking, and maintenance area may already be part of an existing facility. A runoff collection system may not be needed if the runoff can be channeled into a sewage system.

The areas that need to have a stable base are the mixing, composting pad, and screening. Materials that can be used for the base are gravel, crushed rock, asphalt, concrete, or fly ash. Concrete is the preferred material.

In arid areas with high winds, precautions need to be taken to avoid excessive dust. A shelter belt can greatly reduce the wind velocity within the site. Unpaved areas may require watering to reduce dust.

Land area requirements are estimated at 1 ha for each 12 dry tons daily (total solids) of night soil or sludge. This will provide for mixing, piles, screening, drying, curing, and storage. If extended piles are used, the figure is about 1 ha for each 15 dry tons daily.

Types of Equipment for Composting

Equipment needed for a composting operation include: (1) front-end loader; (2) mixing equipment; (3) screening equipment; (4) blowers; and (5) thermometers. Brief descriptions are given below:

Type of equipment	Specifications or model
1. Front-end loader	Rubber wheeled, 2.7-m^3 bucket or larger. Approximately 150-horsepower.
2. Mixing equipment options	
Tractor & rototiller	Standard farm equipment
Easy over compost turner and tractor	Mounted on tractor
Pug mill	Stationary mixing material needs to be fed into mill. Conveyers, hoppers, etc., may cost an additional $30,000 or more.
3. Screens, trommel, or shaker	Specifications to depend on capacity needed; 7 to 9-mm opening.
4. Blowers fans	1/3-horsepower; 115-v, 220 to 230-mm (9 inch) axial vane, centrifugal fan; 3450-rpm, 569-m^3/hr. at 100-mm (4 inch) static pressure
5. Thermometers	Bimetallic dial thermometers or similar with 300- and 600-mm probes

CHAPTER 12

RESOURCE RECOVERY

Human excreta, in whatever form, are a resource that may be conserved and reused rather than discarded. Excreta and sewage contain many essential nutrients for the growth of terrestrial and aquatic plants; often sewage is also a valuable source of water. The anaerobic digestion of excreta yields biogas, which can be used as a source of energy for cooking and lighting. Some form of treatment is always required to reduce the health risks caused by excreted pathogens to an acceptable minimum. The only exception to this is biogas production, but if the digested sludge from the biogas generator is to be reused on the land, additional treatment or storage is necessary unless digestion occurred within the thermophilic temperature range.

There are three principal ways in which excreta and sewage can be reused:

(1) agricultural reuse;

(2) aquacultural reuse; and

(3) biogas production.

There are, however, cultural, institutional, and occasional economic constraints to the reuse of excreta in many areas of the world. Cultural constraints are apparently based on religious custom (rather than religious law) and on aesthetics and convenience. Institutional constraints are found in various kinds of restrictive legislation and in the teaching and practice of conventional, industrial-country sanitation technologies. Economic constraints include availability of low-cost chemical fertilizers, although current trends are for rapid increases in these costs, and economic development in areas of subsistence farming that result in loss of the farmer's willingness to bother with night soil. In any event, the greatest concerns are usually those dealing with infection by pathogens and parasites in the wastes. Accordingly, much of this chapter is taken from Feachem and others (forthcoming), who have reviewed aspects of excreta-related infections. A schematic diagram of a number of possible reuse options is shown in Figure 12-1.

Agricultural Reuse

Agricultural reuse is the most common form of excreta reuse and in many ways is the simplest. There may be risks of infection, however, to those who work in the fields and to those who consume the crops. The latter group includes both man and animals. There may also be problems associated with the chemical quality of the compost, sludge, or sewage effluent coming partly from industrial areas; for example, crops may concentrate heavy metals, and high sodium concentrations can damage the soil structure.

Excreted pathogens present in the waste may reach the field. Different treatment technologies will remove different pathogens to differing degrees. Where sewage effluent is reused, the only treatment processes that will produce an effluent free (or almost free) from pathogens are maturation ponds, land application or sand filtration following waste stabilization ponds, or conventional treatment. Where sludge or night soil are reused, processes that will produce a pathogen-free material are storage/drying for a minimum of 12 months or thermophilic composting.

If pathogens are not removed by these processes, they will be carried to the field. The survival times in soil of excreted pathogens can be generalized as follows:

Pathogen	Survival time
Viruses	Up to 6 months, but generally less than 3 months
Bacteria	Up to 3 years, but generally less than 2 months
Protozoa	Up to 10 days, but generally less than 2 days
Helminths	Up to 7 years, but generally less than 2 years, with few viable after 12 months.

Whether or not the pathogens become attached to the surface of the crops depends upon the method of application and the type of crop. Crops grown on, near, or below the ground are almost certain to become contaminated. Where wastes are sprayed or poured on fields with growing crops, contamination is also certain. Crops may be protected by subsurface irrigation, by drip or trickle irrigation where crops are not on the ground, by irrigating in furrows not immediately adjacent to the crops, or by similar techniques. Alternatively, wastes may only be applied prior to planting, or application may be discontinued one month before harvesting begins, in view of the probability that all pathogens will die before the crops are harvested (see on-crop survival times below). These methods are effective in preventing crop contamination when the applied waste has been properly treated. When a waste rich in pathogens is reused, however, pathogens are likely to reach the crops in significant numbers despite these protective measures.

Once on the crop, pathogen survival is not very long compared to survival in soil. Survival of excreted pathogens on crop surfaces may be summarized as follows:

Pathogen	Survival time
Viruses	Up to 2 months, but generally less than 1 month
Bacteria	Up to 6 months, but generally less than 1 month
Protozoa	Up to 5 days, but generally less than 2 days
Helminths	Up to 5 months, but generally less than 1 month.

The most lethal factors are desiccation and direct sunlight. Survival may be expected to be very much shorter in dry, sunny climates than in humid, cloudy climates.

Survival times are thus quite sufficient for at least some viable
hogens (except, perhaps, protozoa) to be transported into markets, factories,
homes, and subsequently to infect those who handle, process, prepare, or
the crop. A distinction is sometimes made between crops that are eaten
(tomatoes, for instance) and those that are normally cooked (such as
bage). Conservative and good public health policy, however, is to regard
se similarly because, even if the cabbage is eventually cooked, those who
dle and prepare it are still at risk, and pathogens may be transferred to
ps that are eaten raw.

There is much evidence to suggest that, where an excreted infection
highly endemic in a community and where poverty and squalor are found, the
roduction of the particular pathogen into the home on contaminated veget-
es or other crops has a negligible impact on transmission. Where excreted
ections are not widespread in a community and where there are improved
ndards of hygiene and housing, however, the introduction of contaminated
ps into the home may be the major transmission route for some excreted
nogens. This can be illustrated in the following way.

Imagine a town of moderately wealthy people who live in houses with
er connections and flush toilets. Outside this town there is a village
re people are extremely poor, houses have earth floors, water is drawn
n an open well, and there is no adequate excreta disposal system. The main
rce of income for these villages is the cultivation of vegetables for sale
the town. The villagers also use the vegetables themselves as a subsis-
te crop. These vegetables are fertilized by untreated excreta collected
the village and by sewage sludge obtained free of charge from the treatment
ts on the outskirts of the town. Let us consider infection with <u>Ascaris</u>
<u>bricoides</u>. The prevalence of ascariasis in the town is only 8 percent and
principal means of entry of viable <u>Ascaris</u> ova into the home is on the
etables bought from the villages. Transmission among the wealthy towns-
is not taking place since their excreta are flushed away and high stand-
s of hygiene prevail. The prevalence of ascariasis in the village is 68
cent. Transmission occurs intensively in the village and particularly in
home. The house floor and yard are contaminated with viable ova from the
s of infected children. Most transmission is unconnected to the contami-
d vegetables, which the villagers also eat. If the supply of contaminated
tables suddenly ended, the transmission of ascariasis in the town would
educed very substantially, whereas the village would be unaffected.

There are also potential health risks to those who work in excreta-
ilized or sewage-irrigated fields. The limited epidemiological evidence
is available indicates that those who work in fields contaminated by
eted pathogens are at greater risk than others. Also, in many agricul-
l communities, practically the whole population works in the fields at
time of the year, and so all may be exposed to the risk (although not
lly so). The only sure way to protect the health of the agricultural
ers is to use only wastes that have been properly treated.

A special problem regarding the health of agricultural workers occurs when spray irrigation of sewage effluent is used. Aerosol droplets containing enteric bacteria have been reported to travel up to 1.2 km, and bacteria are more infective (i.e., have a lower infective dose) when inhaled than when ingested. Aerosol particles may also carry viruses and cause infection by inhalation. Thus spray irrigation may cause infection by inhalation in those who work in the fields or live within 1 km of them and whose health is already stressed by problems of nutrition, shelter, and personal hygiene.

An additional health problem is that associated with cattle that graze on sewage-irrigated pastures or that are fed fodder crops grown in excreta-fertilized or sewage-irrigated fields. Although the pathogens of a variety of animal diseases have been detected in sewage, they occur in very small numbers, and transmission of these diseases by sewage is of negligible veterinary import. There is one principal exception to this: beef tapeworm (_Taenia saginata_). This helminth circulates between man and cattle and infection _only_ continues when cattle eat _Taenia_ eggs that humans have excreted. Therefore, any excreta disposal or reuse technology that brings cattle into direct contact with human excreta may promote the transmission of the disease unless adequate treatment is provided. _Taenia_ ova are very hardy, being surpassed only by _Ascaris_ ova in their ability to survive outside the host. They may survive in soil or on pasture for over 6 months. Their removal from sewage will require either the use of waste stabilization ponds or tertiary treatment in the form of sand filtration or lagooning. Removal from sludge requires either a thermophilic process or retention for approximately 1 year. It should be noted that the prevention of cattle's exposure to untreated human excreta is crucial because beef tapeworm is an important health problem in both man and cattle in highly endemic areas.

To eliminate health risks associated with the agricultural reuse of excreta and sewage, the wastes should be treated to the following standards for sewage effluents:

Pathogen	Standard
Fecal coliform bacteria	<100 per 100 ml
Fecal streptococci	<100 per 100 ml
Protozoa	Absent
Helminth ova and larvae	Absent

sludges and composts:

Pathogen	Standard
Ascaris ova	200 per 100 g and <5 percent viability

The standards for fecal coliform and streptococci may be relaxed to <1000 per 100 ml if only fodder or industrial crops are irrigated. No figures are given for protozoa and helminths in effluents since 100 percent elimination can be confidently obtained if waste stabilization ponds with a total retention of 20 days or more are used, which is usually necessary to ensure the required removal of fecal bacteria. In areas where ascariasis is absent (these are very rare in developing countries), the ova of either Taenia saginata or Trichuris trichiura or other appropriate helminth indicator organisms should be used.

Aquacultural Reuse

Human excreta can be used to promote the growth of aquatic plants and animals. This practice is termed aquaculture. Four main types of aquaculture are practiced:

(1) freshwater fish farming;

(2) mariculture (the culture of marine animals such as fish, shellfish, and shrimp);

(3) algal production; and

(4) aquatic plant (ova crophyte) production.

Of these, freshwater fish farming is the most common (especially in Asia) and also the easiest. Mariculture is by its nature restricted to coastal communities; it is not as widely practiced as freshwater fish farming. The production of microalgae and aquatic macrophytes has received considerable research effort, but current knowledge is still very limited. Algal harvesting is a complex and expensive process in practice and there are doubts that the yields from small experimental ponds can be achieved in large operational ponds. Although practiced traditionally in a few parts of the world, the fertilization of aquatic macrophytes with excreta and sewage (and its converse, the treatment of excreta and sewage by aquatic macrophytes) are processes that have not yet been fully economically or technically evaluated.

Freshwater Fish Farming

Freshwater fish farming is the only aquacultural reuse process about which enough is known to consider it for widespread replication. Cultured fish are the major source of animal protein for many low-income communities in countries in the Far East, where the most common method of fish pond fertilization is the use of human and animal excreta. Even so, engineers and others involved in sanitation program planning are strongly advised to consult with local fishfarmers and other specialists before embarking on the design of fish ponds. Training of local personnel in the proper management of fish ponds is also essential.

There are three distinct health problems assocated with fish farming in excreta- or sewage-fertilized ponds:

(1) the passive transference of excreted pathogens by the fish, which become contaminated in the polluted water;

(2) the transmission of certain helminths whose life cycles include fish as an intermediate host; and

(3) the transmission of other helminths with life cycles involving other pond fauna, such as the snail hosts of schistosomes.

The first of these problems is a cause for concern throughout the world, whereas the second and third apply only in areas where particular eating habits are found and where the helminths concerned are endemic.

Fish may passively carry human pathogens in their intestines or on their body surfaces, and these pathogens may subsequently infect people who handle, prepare, or eat the fish. There is little risk to fish eaters, except in areas where fish are eaten raw or partially cooked. Thorough cooking will destroy all excreted pathogens.

The second health problem associated with fish farming is the transmission of worms parasitic to man that have an intermediate fish host. The most important of these are Clonorchis sinensis (Oriental liver fluke) and the related species Opistorchis viverrini and O. felineus, which are the only species associated with excreta-fertilized fish ponds. They are intensively transmitted where fish is eaten raw or only partially cooked. Fish cooking must be thorough to kill the encysted larvae, and most fish preservation and pickling techniques have little effect. Where fish are grown in pretreated or presettled sewage, Clonorchis eggs will have been removed by sedimentation. Clonorchis eggs are fragile and die if stored for a few days in night soil. Seven days' storage prior to pond enrichment is a sound strategy for the control of this infection. It must be noted, however, that there are other important definitive hosts apart from man (such as dogs and cats), so that the control of human excreta may only partially reduce transmission.

To summarize, fish farming using excreta or sewage carries with it the hazard of passive carriage of a range of pathogens and, in some parts of the world, of Clonorchis transmission as well. Control measures are as follows:

(1) enrich ponds only with settled sewage or stored night soil or sludge;

(2) allow the fish to reside in clean water for several weeks prior to harvesting;

(3) clear vegetation from pond banks to discourage snails, which are the first intermediate host of Clonorchis (this also eliminates other helminthiases involving snails, such as schitosomiasis);

(4) promote good hygiene in all stages of fish handling and processing; and

(5) discourage the consumption of undercooked fish.

The adoption of all these control measures will eliminate (or, at least, reduce to a low, acceptable level) the health hazards associated with the aquacultural reuse of human wastes and so permit the production of valuable, pathogen-free protein at low cost.

Although the number of fish species that have been successfully grown in excreta- and sewage-fertilized ponds is large, two groups are the most important: carp and tilapia. There are several species of carp and tilapia, the most useful being those that feed directly off the microalgae that grow profusely in fertilized ponds; these include the silver carp (*Hypophthalamichtys molitrix*), the bigear (*Aristichthys novilis*), and the two tilapia, *Sarotheroden mossambicus* and *S. niloticus* (formerly called *Tilapia mossambica* and *T. nilotica*). In India different species of carp are used for fish farming; the four most important are *Catla catla*, *Cirrhinus mrigala*, *Labeo rohita*, and *L. calbasu*.

Yields of carp in fertilized ponds vary from 200 kg/ha/year in rural subsistence ponds to above 1,000 kg/ha/year in carefully managed commercial ponds; yields of tilapia are even higher, 2,000-3,000 kg/ha/year in well-maintained ponds. Tilapia are prolific breeders; in order to eliminate breeding in fish ponds, which reduces yields, the ponds should be stocked with fish of only a single sex. This can be readily achieved by using hybrids of male *S. mossambicus* and female *S. niloticus*, a cross that produces only male fish. Fish yields can be increased by several techniques. Ducks can be reared on the ponds, and their feces provide additional nutrients for the pond algae. This increases fish yields by as much as 50 to 100 percent. Other species of fish that occupy different ecological niches in the pond can be introduced; for example, the common carp (*Cyprinus carpio*) and the grass carp (*Ctenopharyngodon idella*) feed primarily on benthic zooplankton and aquatic weeds, respectively. This process is known as "polyculture," and fish yields of up to 5,000 to 7,000 kg/ha/year can be achieved, especially if supplemental feeding with grass, other vegetation, rice bran, groundnut cake, and the like is practiced.

Basically the construction and physical maintenance of fish ponds is the same as that required for waste stabilization ponds. Depths are usually >1 m to prevent vegetation from emerging from the pond bottom; deep ponds (>2 m) are disadvantageous since there is little oxygen, and hence few fish, in the lower layers.

There is, however, little information available on the range of retention times that should be provided in fish ponds fertilized with sewage effluent. Too short a retention time may waste nutrients, and with long retention times the nutrient supply may be insufficient for optimum yields of fish. The retention time depends on the mean doubling time of the algal species present and the grazing rate of the fish. Generally 1 to 5 days may be required, but this needs to be determined by experiment.

With ponds that are fertilized with stored excreta or with the effluent from a low-flow night-soil treatment pond, the retention time in the fish pond is unimportant. What matters is the correct rate of supply of nutrients; regular batch feeding on an empirically determined basis is recommended.

It is possible to grow carp and tilapia in maturation ponds. Yields are in the range 200 to over 1000 kg/ha/year, depending on management (stocking density, frequency of harvesting). Facultative ponds should not be used for fish culture since the concentration of dissolved oxygen often falls, especially at night, to too low a level. Air-breathing fish such as catfish and snakeheads, however, can be grown in facultative ponds; considerable success has been obtained in India and southeast Asia with several species that are highly prized for their nutritional and supposedly therapeutic value.

The Pacu, a species of freshwater fish found in the Amazon basin, is showing great promise in aquaculture systems. The Pacu is both a filter feeder and a herbivore, can gulp air during periods of low dissolved oxygen, and both grows rapidly and has a higher ratio of edible flesh to total body weight than other traditional species (50 percent versus 35 percent for carp). Use of this fish is still in the experimental stage, but all results look promising.

Health risks can be reduced to acceptable levels if the fish are transferred to clean water depuration ponds for several weeks prior to marketing.

Biogas Production

When organic wastes are digested anaerobically, a mixture of methane, carbon dioxide, and other gases is given off. This gas has become known as "biogas" and can be produced on various scales by different technologies. In conventional sewage treatment works, anaerobic sludge digestion produces biogas that is sometimes used to heat the digestors or for some of the other energy needs of the works. The term "biogas production," however, is usually used to describe the production of methane on a small scale by individual farmers, communes, or rural institutions in developing countries.

Biogas plants are found in large numbers in China, and it is probably in this country that the technology has become most developed. Significant numbers are also in operation in India, Korea, and Taiwan. The units are fed with diluted animal feces, with or without human excreta and with or without vegetable refuse. The effluent slurry is commonly reused in agriculture, and it can be used to enrich fish ponds. The gas is used primarily for domestic cooking and lighting. The dung from one medium-size cow, or similar animal, can produce around 500 liters of gas per day; it contains 50 to 70 percent methane, and its calorific value is around 4 to 5 kcal/liters. In contrast, human excreta yields only 30 liters of gas per person daily. The process is very sensitive to temperature. In the mesophilic range, optimum gas production occurs at around 35°C. In rural areas digesters are not heated, although they may be buried, and so they operate in their ambient temperatures. Gas production falls off considerably at lower temperatures.

There are several designs for rural biogas plants. Construction and operation requirements for some of the designs are presented by the U.S. National Academy of Sciences (1976). Two designs are shown in Figure 12-2. The Chinese design is advantageous in that it contains no moving parts, avoids the need for a metallic gasholder (which has corrosion problems), and permits the gas to be stored at a relatively constant pressure. Its main disadvantage is that its open liquid surface can permit mosquito breeding, although this can be prevented by adding a thin layer of kerosene.

The process design of biogas plants is empirical. Loading rates vary between 0.5 and 3 kg of volatile solids/m^3 digester volume per day, [1] and retention times of 5 to 30 days are common. At the present time it seems prudent to adopt a retention time of 30 days as the controlling process design parameter. Gas production may be expected to be around a third to a half of the digester volume per day if the digester is operated semicontinuously (i.e., fed daily or twice daily). Semicontinuous operation is preferable to batch feeding because the rate of gas production is fairly constant.

The material added to the biogas plant should have a carbon:nitrogen ratio in the range 10:30, and preferably 20:25. Night soil has a C:N ratio of 6:10 and so, for efficient operation of the unit, requires the addition of material with a high C:N ratio, such as leaves, grass, straw, or bagasse. Commonly biogas units in rural areas are designed for cow dung (which has a C:N ratio of 18:25), and the relatively small quantities of human excreta from a few households can be added without undue effect. The feed material should have a solid concentration of about 10 percent, and thus usually some dilution is needed; one volume of animal dung is commonly diluted with one volume of water.

Social, Institutional, and Economic Aspects

The health and technical requirements for a safe and productive resource recovery process have been described above. Much less is known about the equally important social and institutional requirements, and few good economic evaluations have been made for reuse schemes. The real test of any reuse product is whether it is demanded by, and can be delivered to, an ultimate consumer at a price he is willing to pay. The social and cultural factors that influence people's attitudes toward recycled waste products vary widely around the world and are not readily changed. Therefore it is imperative that a careful market study be carried out by behavioral scientists and economists prior to the development of resource recovery schemes.

Reuse processes require careful management, not only to reduce the health risks to acceptable levels but also to organize the delivery and retailing aspects as well as traditional collection and treatment tasks. While well-run municipalities may be cost conscious and attempt to minimize expenditure, they normally lack the incentive and entrepreneurial skill to manage a revenue-producing operation successfully. Often it will be more advantageous for a municipality to contract out excreta and sewage reuse processes to the private sector where these skills are more likely to exist.

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1. Equivalent to approximately 6 to 40 kg cow dung (wet weight) or 14 to 66 kg night soil (net weight) per m^3 per day.

It should be remembered, however, that the economically appropriate test of a reuse process is not that it make a positive profit, but only that its net cost be lower (in terms of discounted cash flow) than that of other treatment and disposal alternatives with or without reuse products. If the private sector is to be involved in the operation of the reuse scheme, this may mean that the municipality will have to pay the private firm a commission (based on the lowest competitive bid) rather than expecting to sell a franchise.

Figure 12–1 Reuse Potential of Wastes

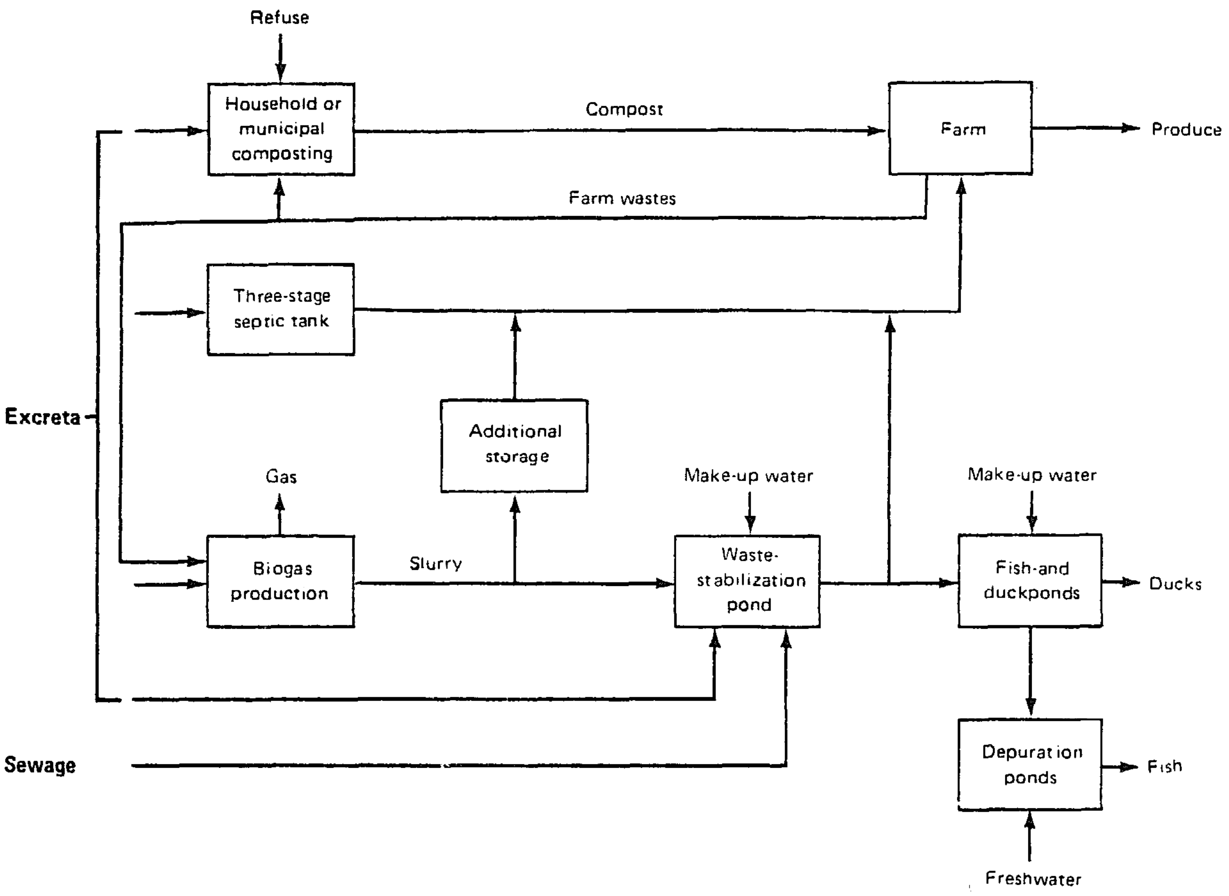
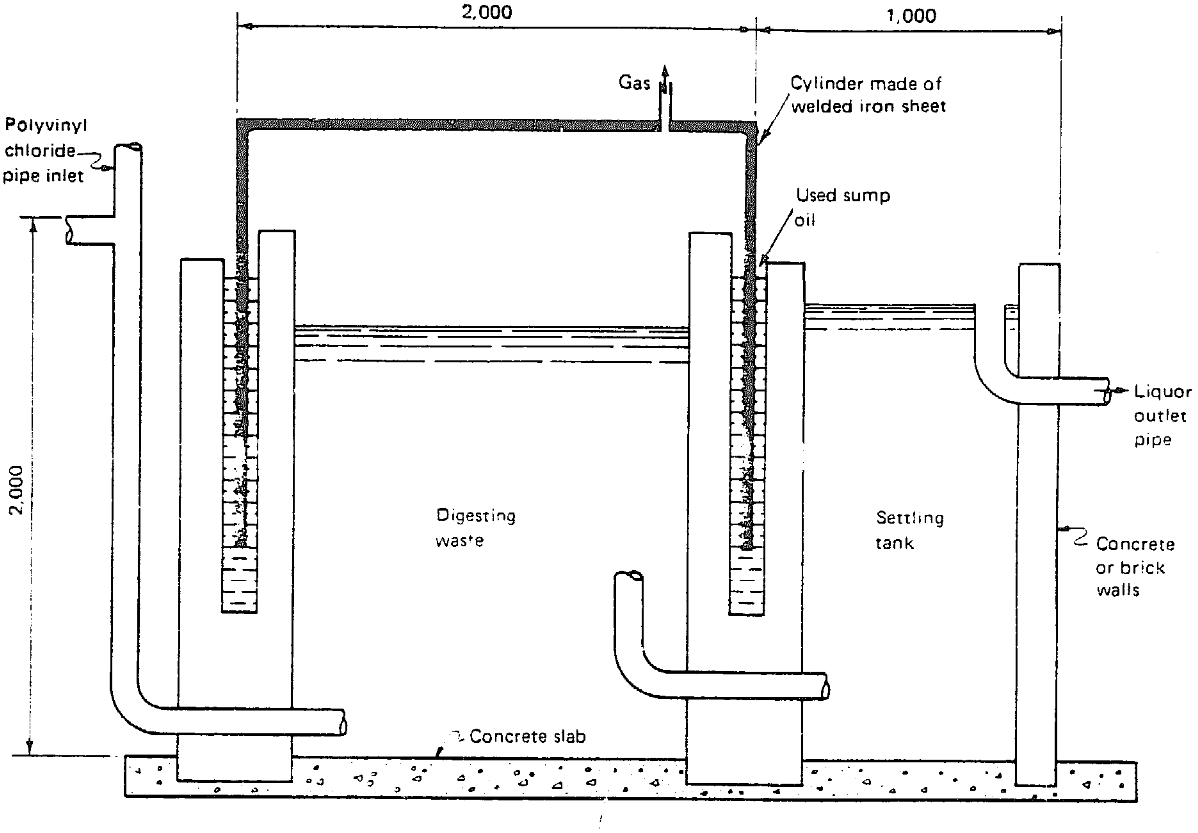
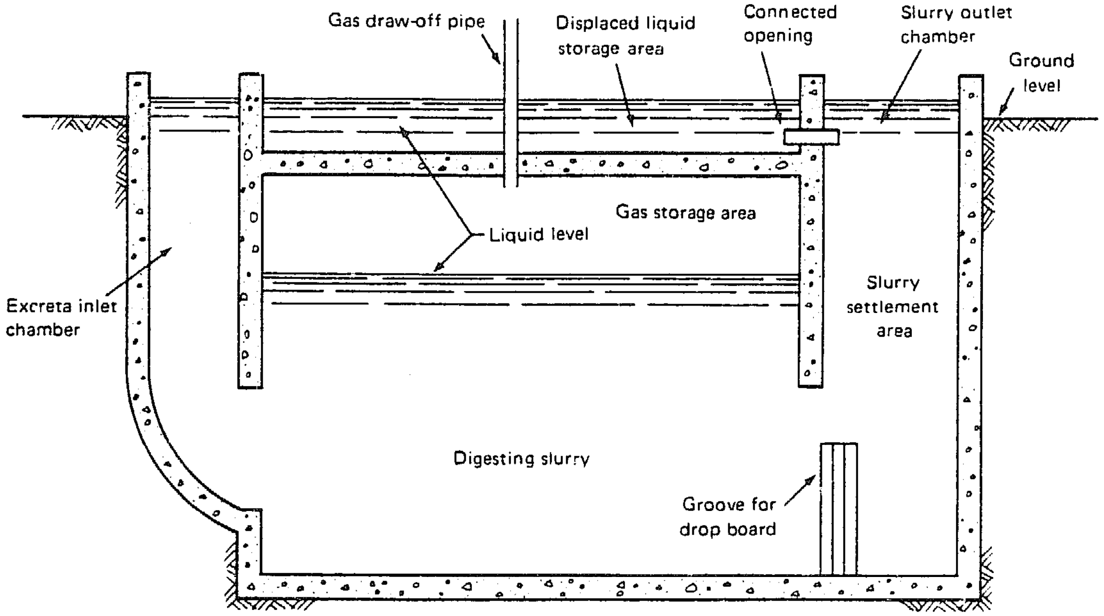


Figure 12 – 2 Schematic of Typical Biogas Digesters (millimeters)



Floating metal gasholder



Chinese design

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