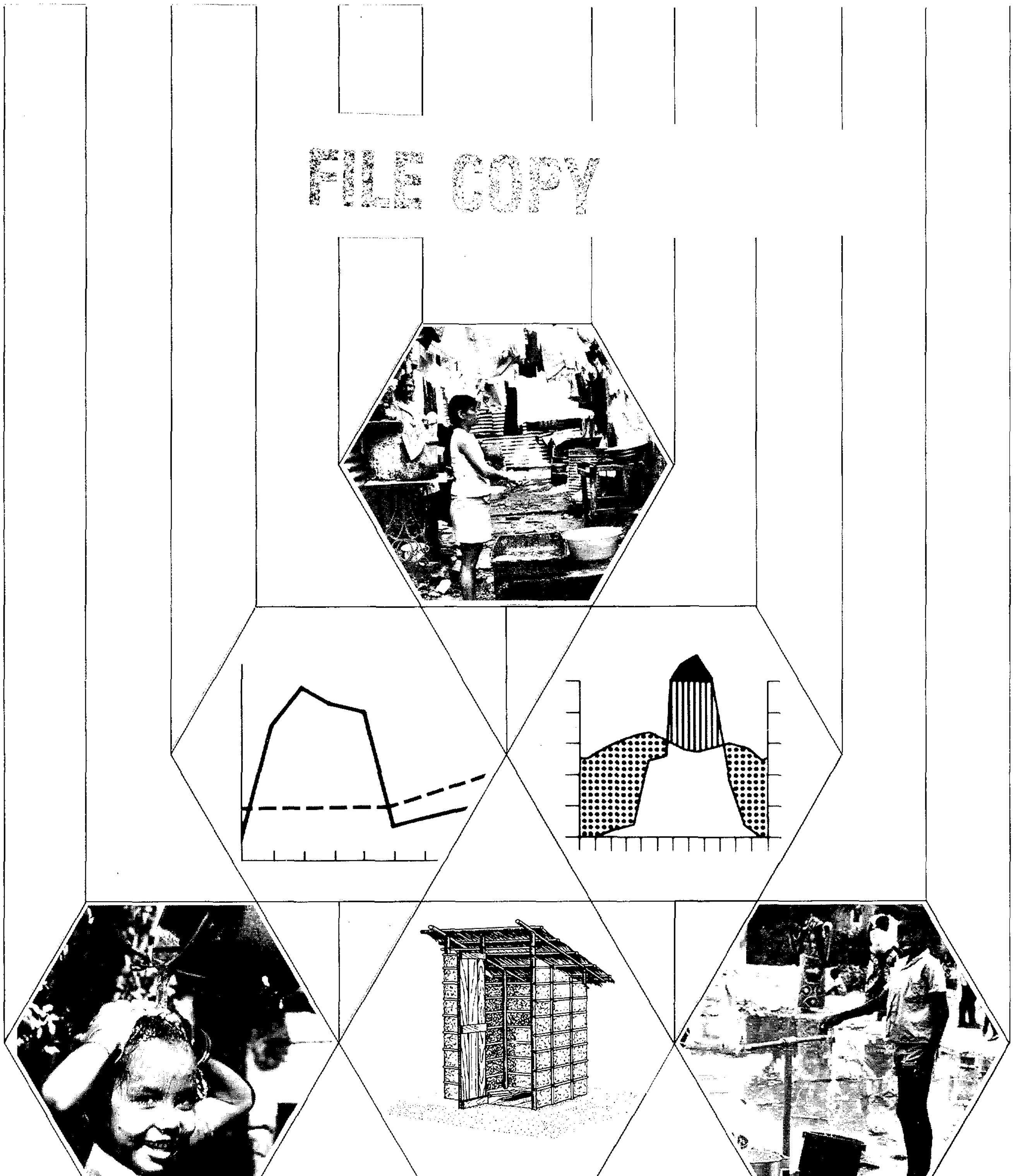
Appropriate Sanitation Alternatives
A Technical and Economic Appraisal

John M. Kalbermatten • DeAnne S. Julius • Charles G. Gunnerson



World Bank Studies in Water Supply and Sanitation 1

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WORLD BANK STUDIES IN
WATER SUPPLY AND SANITATION
1

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Contents

Figures

Maps

Tables

Foreword

DESPITE THE IMPRESSIVE LEVEL of economic growth the developing countries as a whole have achieved over the past quarter century, most of the people in these countries do not have a safe water supply or even rudimentary sanitation. Immediate investment costs for providing these services at the standards which prevail in developed countries are estimated at over US$800,000 million. Corresponding operating costs are projected at another US$10,000 million per year. These amounts vastly exceed the resources available for the sector. To help address this problem, a two-year research project to develop more appropriate (that is, lower-cost) technologies for water supply and waste disposal was undertaken by the World Bank in 1976–78. Meanwhile, the member countries of the United Nations have declared the 1980s to be the International Drinking Water Supply and Sanitation Decade, with the objective of satisfying for all populations of the globe two of the most basic human needs—clean water and the sanitary disposal of human wastes.

The Bank's research revealed the technological, economic, environmental, and institutional interdependence of water supply, sanitation, and health. Waste disposal technologies costing as little as one-tenth the amount of conventional sewerage were identified. Means to ensure high health and environmental benefits were developed. Emphasis was also given to the effects of water service levels upon waste disposal options and, where applicable, to opportunities for recovering some of the costs by physically recycling the water and fertilizer components of the wastes.

This is the first of a series of volumes that document the Bank's research findings. Based on case studies in thirty-nine communities around the world, it presents to planning officials and senior policy advisers a technical and economic assessment of the many sanitation options that are available and appropriate to conditions in developing countries. Other volumes in the series include a planning and design manual for project engineers, analysts, and technicians and a compilation and synthesis of health and disease factors important in sanitation system planning and implementation. Their publication is particularly timely at the beginning of this decade. If the twin objectives of economic growth and the eradication of absolute poverty are to be met, the nations of the world must ensure that everyone has access to safe water and adequate sanitation. It is to universal access to the latter that this volume is dedicated.

WARREN C. BAUM
Vice President, Central Projects Staff
The World Bank

Preface

OVER THE PAST DECADE, the focus of development planners on economic growth has broadened to include a parallel concern with the distribution of the benefits made possible by that growth. In his president's address to the Board of Governors of the World Bank at its 1980 annual meeting, Robert S. McNamara reiterated that, to achieve the twin objectives of economic growth and the eradication of absolute poverty, countries must do two basic things: assist the poor to increase their productivity and ensure their access to essential public services.

Among these essential public services are water supply and waste disposal. Few other services contribute as much to an improvement in health and living standards as does the provision of an adequate supply of safe water and the means for sanitary disposal of waste. It has become apparent, however, that development projects must be specifically designed to reach the urban and rural poor if the poor are to be provided with services that they can afford and that meet their needs.

In particular, sewerage—the conventional method of human waste disposal in the developed countries—requires massive investments of both foreign and local capital that generally are not available in the developing nations. Where sewerage systems have been built, they often have required charges to the consumers that were beyond consumers' ability to pay. In acknowledgment of the limitations of traditional solutions, the World Bank in 1976 launched a two-year research project entitled "Appropriate Technology for Water Supply and Waste Disposal in Developing Countries." The objective of the project was to identify and evaluate alternative sanitation technologies for their potential to meet the needs and match the resources of project beneficiaries.

To accomplish this, the health, social, institutional, as well as the technical and economic aspects of the various technologies had to be considered. The overall project has consequently generated a variety of subsidiary research by specialists in different disciplines, and its findings are being issued in a collection of publications entitled "World Bank Studies in Water Supply and Sanitation," of which this appraisal is number 1. Other publications in this collection include:

John M. Kalbermatten and others, *Appropriate Sanitation Alternatives: A Planning and Design Manual,* World Bank Studies in Water Supply and Sanitation, no. 2

Richard G. Feachem and others, *Sanitation and Disease: Health Aspects of Excreta and Wastewater Management,* World Bank Studies in Water Supply and Sanitation, no. 3

Further publications in the collection will be issued as ongoing research is completed. In addition, the Transportation, Water, and Telecommunications Department (TWT) of the World Bank maintains a series of reports— under the main title *Appropriate Technology for Water Supply and Sanitation*—available from the Bank's Publications Unit. Subtitles of volumes in this series are as follows:

- vol. 1: *Technical and Economic Options,* by John M. Kalbermatten, DeAnne S. Julius, and Charles G. Gunnerson
- vol. 1a: *A Summary of Technical and Economic Options*
- vol. 2: *A Planner's Guide,* by John M. Kalbermatten, DeAnne S. Julius, Charles G. Gunnerson, and D. Duncan Mara
- 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
- 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 World Bank/International Development Research Centre publica-

tion, from the IDRC, Ottawa, Ontario, Canada]

- vol. 5: *Sociocultural Aspects of Water Supply and Excreta Disposal,* by Mary Elmendorf and Patricia Buckles
- vol. 6: *Country Studies in Sanitation Alternatives,* 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: *Low-Cost Design of Water Distribution Systems,* by Donald T. Lauria, Peter J. Kolsky, and Richard N. Middleton
- 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, and Charles G. Gunnerson
- vol. 12:*Low-Cost Water Distribution—A Field Manual,* by Charles Spangler.

The main purpose of this appraisal is to summarize the technical, economic, health, and social findings of the research, and to discuss the aspects of program planning necessary to begin implementation of the findings. It is, therefore, directed primarily toward planning officials and advisors for sector policy in and for developing countries. Although the focus is primarily on sanitation options (because water supply technology is better known and understood), information on levels of water service is included because water use is a determining factor in waste disposal. Technical details and designs are presented in *Appropriate Sanitation Alternatives: A Planning and Design Manual,* forthcoming as a complement to this volume.

The study presents the results of two years of field studies undertaken by the World Bank in thirty-nine communities in fourteen countries of the developing world. A bibliographic search was initially conducted for information on nonconventional options, but only about 1 percent of the published technical literature on wastewater related to technologies other than sewerage. Case studies carried out by local engineers, economists, and behavioral scientists thus formed the backbone of the research.

The first and most important finding of the case studies was that there are many technologies between the unimproved pit privy and conventional sewerage that can be recommended for replication on a wide scale. In all, five types of household (on-site) systems and four types of community systems were identified, and many variations of each type were observed. Improved designs were prepared for several of these, and for only one technology (bucket latrines) was it concluded that introduction of a system to new sites should be avoided. Two of the other technologies, aquaprivies and communal facilities, were found to have limited applicability because of social factors. All of the remaining technologies (improved pit latrines, pour-flush (PF) toilets, composting toilets, modified septic tanks, vault and cartage, small-bore sewerage, and conventional sewerage) can be recommended (subject to the physical conditions of the site and the social preferences and economic resources of the beneficiaries) for adoption. Except in unusual circumstances, both scattered, rural and densely populated, urban communities should find themselves with two or more technically feasible options, each with a range of design alternatives.

Another important technical contribution of this research has been the design of "sanitation sequences": step-by-step improvements leading from one technology to another and designed to minimize costs over the entire sequence. These enable a community initially to select one of the low-cost technologies in the knowledge that, as the community's socioeconomic status improves, the technology can be upgraded without wasting the initial investment. It is noteworthy that none of the sanitation sequences has conventional sewerage as its final improvement. In urban areas, the final upgrading is generally to a low-volume flush toilet connected to a vault that overflows into a small-diameter sewer. From the user's viewpoint, the only difference between this system and conventional sewerage is the size of the toilet tank in the bathroom. Yet the cost savings, particularly if installation proceeds in stages, are significant. Over a thirty-year period the total present value cost of this alternative system is about one-half that of conventional sewerage. Its environmental cost is also likely to be significantly lower than that of sewerage because its eventual waste discharge is less. As this example indicates, the critical element in an economic solution to providing sanitation is the reduction of nonessential water use. (Toward this end, work is now underway to adapt water-saving showerheads and other appliances for use in developing countries.) A corollary to this conclusion is that schemes for water supply, with or without sanitation, should explicitly consider, in the design and cost comparison of alternative service levels, the requirement to dispose of the wastewater created.

In addition to these technical findings, the research has produced a new and promising approach to the problem of linking potential health benefits to improvements in environmental sanitation. Rather than tackling yet again the intractable problem of quantifying health benefits, this research focused directly on the transmission process of excreta-related disease and the relation of that process to the various sanitation alternatives. The Ross Institute of Tropical Hygiene of the London School of Hygiene and Tropical Medicine was contracted as part of this study to develop an environmental classification of excreta-related infections that, together with a basic understanding of the factors important in disease transmission, would enable the planner and engineer to maximize the health benefits of whatever technology is chosen. The means of so doing include both the incorporation of specific design features and the supplementation of "hardware" with precisely directed educational campaigns for users. [In the process of developing the environmental classification, Dr. Richard G. Feachem and others at the Ross Institute conducted a comprehensive review of relevant literature and have produced a unique reference work on the subject (*Sanitation and Disease*, Part One) as well as an original and insightful analysis of the relation between sanitation and excreta-related infections (*Sanitation and Disease*, Part Two and the references therein).]

That alternative technologies exist and that they can be designed to maximize health benefits still leaves the planner with two important questions: what do the technologies cost, and what complementary inputs do they require for successful implementation? The costs collected from a statistically based, case-study approach such as this one are bound to vary widely from one community to another even for identical technologies. When the problem is compounded by the fact that no two observed pit privies, for example, were exactly alike in their design or construction, it is obvious that precise measures of cost sensitivities cannot be obtained. Yet, by applying a consistent methodology to all case-study calculations and by deriving economic rather than financial costs, a broad cost comparison of different technologies was possible.

The nine technologies studied formed three distinct cost groupings. Five of them cost less than $100 annually per household (including both capital and recurrent costs); two technologies cost between $150 and $200 annually per household; and two (septic tanks and sewerage) cost more than $300 annually per household. (All cost figures in the study refer to 1978 U.S. dollars.) The ratio of lowest to highest cost of the systems was 1:20.

The two most important influences on total household costs were factors that have often been ignored in engineering analysis: on-site household costs (for example, internal plumbing) and the cost of flushing water for water-carried systems. The former was important for all technologies and never accounted for less than 45 percent of total household costs on an annual basis; the latter was most important for sewerage and septic tank systems. Where the economic cost of water is high, the payoff from designing systems with low requirements for flushing water is large.

The findings and recommendations of this appraisal are based on surveys of relevant literature (see Feachem and others, *Sanitation and Disease*, and Rybczynski, Polprasert, and McGarry, *Low-Cost Technology Options*), an evaluation of sociocultural factors (see Elmendorf and Buckles, *Sociocultural Aspects of Water Supply*), detailed field studies (see Kuhlthau, *Country Studies*, and Lauria, Kolsky, and Middleton, *Low-Cost Design*), 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 Yves Rovani, director of the Energy, Water, and Telecommunications Department at the time the research was done and currently director of the Bank's Energy Department, and the valuable review and direction provided by Kim Jaycox, chairman of the Project Steering Committee. Advice and expertise in particular areas were freely provided by Jerry Warford and Harold Shipman, two of the early supporters of the project, and by William Cosgrove, Art Bruestle, Fred Hotes, Johannes Linn, Ragnar Overby, John Courtney, and Charles Weiss. In addition, David Bradley and Richard Feachem of the Ross Institute of Tropical Hygiene, D. Duncan Mara of the University of Leeds, Gilbert and Anne White of the University of Colorado, and Mike McGarry of the International Development Research Centre helped us considerably in shaping our approach to the health and social aspects of the study and in developing the algorithm for technology selection.

Special thanks are due to the field consultants whose tireless efforts to obtain and evaluate information under diverse, and sometimes difficult, conditions made possible our empirical analysis. Their individual contributions are acknowledged in the *Appropriate Technology* publications for which they were responsible, but we would like to extend our particular thanks to Kenneth Iwugo, who was responsible for the case studies of Nigeria, Ghana, and Zambia; Ng Kin Seng, who did the work on Malaysia and the island of Taiwan; S. S. Soesanto for the excellent work of her team in Indonesia; Dong Min Kim for his Korean study; Mary Elmendorf and Chuck Pineo for their work in Nicaragua; Samir El Daher and Beshir Mohammed El Hassan, who undertook the Sudan study; Shohei Sata and Katsuyoshi Tomono of Nihon Suido Consultants for their important work on the Japanese cities; Raphael Rodriguez, who undertook the work on Colombia; and Mike Blackmore and his team in Botswana. In addition, Mei-Chan Lo and Robert T. C. Lee, both of Taiwan, were instrumental in helping us evaluate the potential for wider replication of the interesting intermediate technologies for sanitation that were studied there. Harvey Ludwig and Saul Arlosoroff assisted us in the evaluation of various technologies.

This book could not have been produced without the dedication and cooperation of the secretarial staff: Margaret Koilpillai, Julia Ben Ezra, and Susan Purcell. David Dalmat and Sylvie Brebion's efficiency in coordinating the graphics and other aspects of this publication with those of the other volumes in the Studies of Water Supply and Sanitation series is greatly appreciated.

Finally, we owe a special thanks to our spouses—Nelly Kalbermatten, Ian Harvey, and Betty Gunnerson—who endured the extra travel and long hours that this research project entailed.

JOHN M. KALBERMATTEN
DEANNE S. JULIUS
CHARLES G. GUNNERSON

Acronyms and Abbreviations

AIC	Average incremental cost
BARC	Beltsville Agricultural Research Center (U.S. Department of Agriculture, Beltsville, Maryland, U.S.A.)
BOD	Biochemical oxygen demand
BOD_5	Five-day BOD (by the standard test)
DVC	Double-vault composting (toilet)
PF	Pour-flush (toilet)
PVC	Polyvinyl chloride
ROEC	Reed Odorless Earth Closet
TACH	Total annual cost per household
VIDP	Ventilated improved double-pit (latrine)
VIP	Ventilated improved pit (latrine)

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1 An Overview

A CONVENIENT SUPPLY of safe water and the sanitary disposal of human wastes are essential ingredients of a healthy, productive life. Water that is not safe for human consumption can spread disease; water that is not conveniently located can reduce the productive time and energy of the water carrier; 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.

Water Supply and Sanitation in Developing Countries

Coupled with malnutrition, these excreta-related diseases take a dreadful toll in developing countries, especially among children. For example, in one Middle Eastern country half of the children born alive die before reaching the age of five as a result of the combined effects of disease and malnutrition. In contrast, only 2 percent of the children born in the United Kingdom die before reaching their fifth birthday. It is invariably 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 the information on how to minimize the ill effects of the unsanitary conditions in which they live. As a result, the debilitating effects of endemic disease lower the productive potential of the very people who can least afford such loss of productivity.

Dimensions of the problem

To understand the magnitude of the problem, one only need consult the data collected by the World Health Organization (WHO) in preparation for the United Nations Water Conference (Mar del Plata, Argentina, Spring 1977). These rough estimates show that only about one-third of the population in developing countries have adequate sanitation services; that is, about 630 million out of 1.7 billion people.[1] Population growth will add to this figure in the 1980s another 700 million people who will have to be provided with some means of sanitation if the goal of the International Drinking Water Supply and Sanitation Decade—adequate water supply and sanitation for all people—is to be achieved. A similar number of people, about 2 billion, will require water supply by the same date. Thus, approximately half a million people daily, from now until 1990, will need to be provided with water and sanitation services.

One of the fundamental problems in meeting this goal is the high cost of conventional sanitation services. General estimates based on 1978 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, an amount totally beyond the ability of the beneficiaries to pay.

In industrialized countries, the standard solution for the sanitary disposal of human excreta is waterborne sewerage. Users and responsible officials have come to view the flush toilet as the absolutely essential part of an adequate solution to the problem of excreta disposal. This technology, however, was designed to maximize user convenience rather than health benefits. Convenience may be an important objective in developed countries, but it has a lower priority in most developing countries. In fact, conventional sewerage has been the result of a slow progress made 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. Decisionmakers are asked to achieve the standards of convenience observed in industrialized countries, but—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. Sewerage could be provided for a few, but at the expense of the vast majority of the population. As a consequence, many developing countries have taken no steps at all toward improving sanitation. The very magnitude of the task has effectively discouraged action.

At the present time the first priority of excreta disposal programs in developing countries must be human health; that is, the reduction and eventual elimination of the transmission of excreta-related diseases. This health objective can be fully achieved by nonconventional sanitation technologies that are much cheaper than sewerage. The goals for the International Drinking Water Supply and Sanitation Decade of the 1980s intentionally do not specify sewerage, but call for the sanitary disposal of excreta—leaving the chosen disposal method to the discretion of individual governments. Similarly, objectives of the Decade include an adequate supply of safe water, but do not specify the methods to be used to achieve the goal. The challenge of providing as many people as possible with the required facilities is to find techniques to achieve these objectives with the resources available.

The constraints

The principal constraints to the successful provision of sanitation facilities in developing countries are lack of funds, lack of knowledge about nonconventional sanitation technologies, and weak institutions with few trained personnel. There is no foreseeable way that waterborne waste disposal, with an average investment cost of around $300 per person, can be made affordable in countries in which annual per capita income averages less than that amount. In addition, and implicit in the decision to provide sewerage, is a decision to provide a water connection to each house. About 40 percent of the water from this connection will be used for no essential purpose but to flush away wastes. Even in the unlikely event of the developed countries' providing massive grant funds towards the initial cost of installing sewerage in the developing world, the costs of operating and maintaining sewer systems and of satisfactorily disposing of the sewage would be prohibitive. Lower-cost solutions have to be found for the majority of people.

The lack of interest in sanitation technologies other than sewerage is in part because of the standardized education of most planners and engineers in developing countries. Engineers are trained in sophisticated (and intellectually stimulating) advanced technology that is, in a sense, self-perpetuating: sewer systems lead to high water consumption and the attendant problems of source development and effluent disposal. Planners feel they have to press for sewerage because without it public health will not be secure. Few sewer systems in developing countries are well maintained. Sewage treatment works commonly discharge effluents in a condition little better (and in some cases worse) than the incoming sewage. In any case, current plant design concentrates on undoing the environmental problems waterborne collection has created rather than on health maintenance through pathogen removal. There is, therefore, little realistic basis for the commonly held view that Western sanitation techniques are the appropriate solution for developing countries. Rather, reeducation of engineers to design for maximum health benefits, and to consider the whole range of available technologies, is essential.

Most municipalities in developing countries have difficulty in attracting and retaining well-trained staff, and in consequence municipal services suffer. The potential for self-help in conventional sewerage is, however, minimal. The adoption of low-cost technologies can capture the strong desire of most people to improve their living conditions, and this motivation can be put to good use. But this implies a change in the role of the municipality; it must become an active promoter and educator because experience makes it abundantly clear that technologies imposed on people without adequate consultation are likely to fail or go unused.

A glimpse of a solution

Given these constraints, it is not surprising that levels of sanitation service in developing countries have remained low. A major effort is needed to identify and develop alternative technologies for sanitation that are appropriate to the conditions in developing countries and are designed to meet health requirements at a cost affordable to the user. Clearly, the solutions also must reflect the communities' preferences.

The identification and design of appropriate excreta disposal systems does not require the invention of new processes or devices. Rather, it calls initially for a review of the historical development of the present technology, a reexamination of the decisions leading to sewerage, and the design of improvements to eliminate problems that caused the abandonment of earlier, low-cost solutions. An examination of how sewerage came about reveals three facts clearly. First, waste disposal went through many stages before sewerage. Second, existing systems were improved and new solutions invented whenever the old solutions were no longer satisfactory. Third, improvements have been implemented over a long period of time and at substantial cost. Sewerage was not a grand design achieved in one giant step but is the end result of progressively sophisticated solutions. It took industrialized countries over a hundred years to achieve their present status in a close matching of needs and the economic capacity to take care of them. With the benefit of hindsight, it should be possible to correct not only some of the shortcomings of previous solutions, but also to develop a sanitation system that can be further improved, step by step, to meet both the user's requirements and economic capacity to pay for improvements.

What is needed is a sequence of sanitation improvements, designed from the outset to provide maximum health benefits while minimizing costs over the long run. If sanitation facilities are to be used, each step of the sequence must consider consumers' preferences and customs of personal hygiene. In fact, sequenced sanitation is likely to be more successful than the immediate installation of sewers has been because it allows the user to progress as he sees fit, to whatever level of convenience he desires and at his own speed, in a reflection of his personal preferences and capacity to install, operate, and pay for the facility.

Fortunately, low-cost alternatives to sewerage exist and work well. When properly constructed and maintained, they provide all the health benefits of sewerage and have fewer adverse environmental effects. They are, in many cases, technologies that had been used for many years in developed countries but were abandoned rather than improved as those countries grew more prosperous. They may not be applicable to parts of the dense, westernized, metropolitan centers of the developing world, where sewerage may remain the most appropriate technology, but they are ideally suited to rural areas, small towns, and metropolitan fringe areas, which closely resemble the environment for which they were originally developed. Their failures are usually attributable to poor design, inadequate education of users, or lack of maintenance—problems that plague sewerage systems as well but can be overcome in developing countries if increased emphasis and attention are given to improving health and sanitation.

An Operational Definition of Appropriate Technology

A large body of literature has developed in recent years on the choice of appropriate technology, particularly in the manufacturing and agricultural sectors. The surge of interest in this topic dates from the publication of E. F. Schumacher's book *Small Is Beautiful* in 1973.[3] Before 1973, the theory of technological choice was written about mostly by economists and was concealed in technical jargon such as "factor proportions"[4] or "induced bias."[5] Schumacher's book served to bring some of the basic ideas into public view.

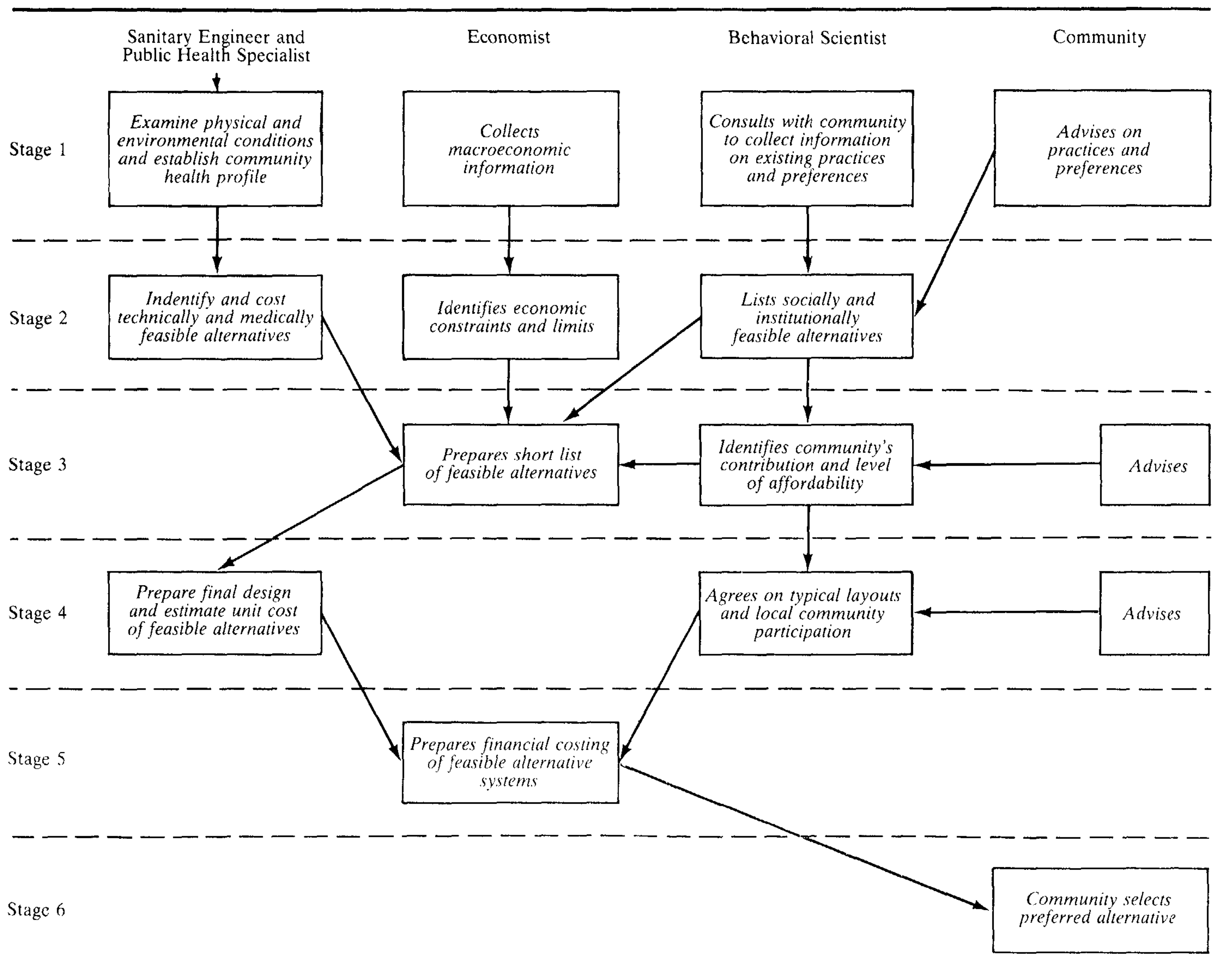
There is no concise and universally correct definition of technological appropriateness; the concept is a relative one, which can only be applied within a particular context. The standards for determining the appropriateness of technology are related to the developmental goals of the country making the choice and to the circumstances of the technology's use. Various rules of thumb have been suggested that call for low capital intensity, simplicity of operation, use of indigenous resources, and so forth, but they are of limited use in comparing diverse technologies, which would rank differently according to each of these criteria, and they are not universally appropriate for all developing countries.

The operational definition used in this study is really an abbreviated description of the process of determining which technology is appropriate in a particular case. An appropriate technology is defined as a method or technique that provides a socially and environmentally acceptable level of service or quality of product with full health benefits and at the least economic cost.[6] This "definition" immediately provokes questions. How does one judge social or environmental acceptability? What is the economic cost of a process? There is an intuitive understanding of the words themselves, but their application is not straightforward. This study looks in detail at the process of identifying appropriate sanitation technology from the technical, economic, health, and social perspectives. The basic philosophy is that only those technologies that pass all these tests are appropriate. The operational definition incorporates long-run benefits and costs by using life-cycle costing and by paying particular attention to the technical potential for upgrading each alternative as the incomes and aspirations of the users grow over time.

The selection process

The process of selecting technology begins by identifying all the technological alternatives available for providing the good or service desired (in this case, sanitation). Within that set of possibilities there will usually be some technologies that can be readily excluded for technical, health, or social reasons. For example, septic tanks requiring large drainage fields would be technically inappropriate for a site with 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. Some technologies may require institutional support that is infeasible in the given social environment. Once these exclusions have been made, the range

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



of technically and socially feasible alternatives that provide full health benefits remains. For these technologies, cost estimates are prepared that consider their real resource cost to the economy. As described in chapter 3, this may involve adjustments in market prices to counteract economic distortions or to reflect developmental goals such as the creation of employment.[7] Least-cost solutions for each technology are determined. On the basis of these economic costs and discussions with government planners, financial costs are prepared for all least-cost solutions. Those alternatives clearly outside the bounds of affordability for consumers are excluded. Because the benefits of various sanitation technologies cannot be quantified, it is impossible for the economist to do more than exclude various alternatives. A single least-cost alternative cannot usually be recommended because there is no way of quantitatively comparing benefits. The final step in identifying appropriate sanitation technology must rest with the eventual beneficiaries. Those alternatives that have survived technical, health, social, and economic tests are presented to the community with their corresponding financial price tags, and the users must decide for which level of service they are willing to pay.[8]

How the technical, health, social, and economic aspects of technological choice are actually coordinated is shown in figure 1-1, although the stages in the figure should not be interpreted too literally. 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 upon technical parameters. Because of these relations between the various boxes in figure 1-1, there must be a close working association among the different actors in the planning process.

For simplicity, it is assumed that separate individuals or groups are responsible for each part, although in practice responsibilities may overlap. In stage 1 of figure 1-1, each specialist collects the information necessary to make his respective test for exclusion. For the engineer, health specialist, and behavioral scientist, this data collection will usually take place in the community to be served. The economist will talk with both government and municipal officials to obtain the information necessary to calculate shadow rates and to determine the availability of grant funds or other means of subsidy. The engineer, health specialist, and behavioral scientist will then apply the information they have collected to arrive at preliminary lists of technically, medically, and socially feasible alternatives. In the third stage the economist prepares cost estimates for those technologies that have passed technical and social tests and selects the least-cost alternative for each. As the fourth step, the engineer prepares final designs and unit costs for these choices. At this point the social information collected in stage 1 should be used to determine, for example, 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 whose technical and economic import may be low but which make a major difference in the way the technology will be accepted and used in the community. The final designs should also incorporate features necessary to maximize the health benefits expected from each technology. Final designs are used in the fifth stage to determine financial costs (based on the availability of national and municipal funding), including how much the user will have to pay for construction and maintenance of each design. Any technology whose total financial cost is more than 10–20 percent of user income probably should be excluded as financially unaffordable. The final step is for the behavioral scientist to present and explain the alternatives and their costs to the community for final selection.

Comparison with the traditional approach

The process above contrasts with that of the typical feasibility study. The conventional team conducting feasibility studies is heavily weighted with engineers. It may contain a financial analyst, but rarely an economist, and almost never a behavioral scientist. The alternative technologies considered are usually only a small subset of the group discussed in this report, and in many cases the terms of reference of the study (written by other engineers) limit the selection to waterborne sewerage with several collection configurations and treatment alternatives. Thus the selection process described in figure 1-1 is short-circuited and moves directly through technical criteria to final design. The conventional study team then prepares estimates of financial costs and writes its report.

The main problems of this customary process are obvious from a comparison with the methods set forth in this study. In the conventional procedure, the most appropriate technologies may never get considered. No checks are made to ensure that the technical solution designed and costed is socially acceptable. By excluding a meaningful economic comparison, the usual method makes no guarantee that the solution offered is the one of least cost for the economy. The decisionmakers are presented at the end with a proposal that has not taken into account their own economic priorities or the ability to pay of their constituents, the ultimate beneficiaries.[9]

The framework suggested in this report for the identification of appropriate technologies is probably more time intensive than that of traditional feasibility analysis. It also requires the recruitment of additional personnel. Thus, a clear case must be made for its superiority in choosing appropriate technologies, and it must be shown that the cost of choosing an inappropriate technology is sufficiently high to warrant a more costly selection process. The case studies of sanitation systems in thirty-nine communities, which form the basis of this report, lead us to believe that there is a very high cost, both in wasted resources and in poorer community health, associated with the imposition of inappropriate sanitation technologies. Part One of this appraisal presents the detailed findings of the community studies.

Notes to Chapter 1

1. "Billion" is equivalent to "thousand million."

2. All cost figures in this study are in 1978 U.S. dollars. See chapter 3 for their derivation.

3. E. F. Schumacher, *Small Is Beautiful* (New York: Harper and Row, 1973).

4. R. S. Eckaus, "The Factor Proportions Problem in Undeveloped Areas," *American Economic Review*, vol. 45 (September 1955), pp. 539–65.

5. C. Kennedy, "Induced Bias in Innovation," *Economic Journal*, vol. 74 (September 1964), pp. 541–47.

6. A more rigorous definition would be the technology for which the net present value of the stream of health and environmental benefits, subject to a constraint on social acceptability, is maximized. The difficulty of quantifying health and environmental benefits, however, prevents such a definition from being operationally useful.

7. An ideal analysis would go beyond economic costing to include income-distributional factors by calculating social costs. Distributional weights, however, cannot be taken into account explicitly in this analysis because benefit quantification is not possible. This is not a significant limitation because the major concern of this study is to identify technologies that are specifically appropriate for the rural and urban poor. The study's case studies themselves were chosen to embody this concern.

8. Because the consumer is presented with financial rather than economic costs, it is important that economic cost *ranking* of the technologies be preserved in deriving financial costs. This may preclude, for example, full construction grants for all technologies regardless of relative construction costs.

9. Blame should not necessarily be placed on the consulting firms who prepare such conventional studies. Often they are guilty of no more than following current practice in a highly competitive field, and they must work within the constraints of their terms of reference. A number of firms, in fact, are already implementing some of the recommendations of this report and routinely use multidisciplinary teams in their work. The obstacles to the choice and adoption of appropriate technologies are discussed in chapter 6.

Part One

Analysis of Field Study Results

2

Technical and Environmental Assessment

INVESTIGATIONS OF SANITATION SYSTEMS on sites in thirty-nine communities around the world have provided a wealth of practical design and operational data upon which a technical assessment of various sanitation alternatives may be based. Although many variations of similar systems were observed, this chapter classifies all of the technologies studied into five types of household systems and four types of community systems. The essential features of each are described, the technical requirements and environmental limitations are discussed, and an assessment is made of the potential for upgrading and widely replicating each. The cost and health implications of the technologies are presented in the following two chapters.[1] For a generic classification of the various sanitation systems, see figure 2-1. A summary of the data on population and service levels characteristic of some of the communities studied is shown in tables 2-1 and 2-2.

Household Sanitation Systems

Pit latrines, pour-flush (PF) toilets, composting toilets, aquaprivies, and septic tanks for use in individual homes are the major types of household sanitation systems. The distinguishing feature of these, compared with the community systems discussed in the next section, is that they require little or no investment in facilities outside individual homesites.

Pit latrines

By far the most commonly observed technology around the world, particularly in rural areas, is the pit latrine (figure 2-1, no. 3). In its most elementary form, a pit latrine has three components: the pit, a squatting plate (or seat and riser), and the superstructure. The pit is simply a hole in the ground into which excreta fall. When the pit is about three-fourths full, the superstructure and squatting plate are removed and the pit is filled up with soil from a new pit dug nearby.

Most of the seven pit latrines evaluated in this study were of the simple, unimproved variety and consequently had both odor and insect (flies and mosquitoes) problems. These undesirable features were almost completely absent in the ventilated, improved pit (VIP) latrine and the Reed Odorless Earth Closet (ROEC) observed in southern Africa.

VIP latrines

In a VIP latrine (figure 2-1, no. 5), the pit is slightly displaced to make room for an external vent pipe. For maximum odor control the vent pipe should be at least 150 millimeters in diameter, painted black, and located on the sunny side of the latrine so that the air inside the pipe will heat up and create an updraft. (Indications are that painting the pipe black may increase the ventilating effect.) If the vent pipe is letting enough light into the pit, and if the superstructure is fairly dark, flies will try to escape through the vent rather than back into the superstructure. Covering the vent pipe with a gauze screen will prevent flies from escaping through that route and thus minimize the health hazard from these insects.[2] Where the user prefers a solid superstructure that cannot be moved, or where space is not available for moving a VIP latrine, a modification—a ventilated improved double-pit (VIDP) latrine—can be used. The VIDP latrine contains two pits, which are dug side by side and are covered by the same superstructure. Use of the two pits alternates, with the squatting plate being moved from the full to the empty pit as necessary. The full pit is emptied not less than twelve months after last use to be ready for renewed use when the second pit is full.

Table 2-1. *Water Service Levels for Selected Study Communities*

	Population		Water service level			
			Types of service[a]		Liters per	Cubic meters
Community	Total	Per hectare	Percent	Percent	capita daily	per hectare daily
East Asia						
1 (rural)	56,000	5.2	13 (W)	87 (H)	271	1.4
2 (resort)	57,000	4.2	28 (W)	72 (H)	208	0.9
3 (suburban)	103,000	79.0	1 (W)	99 (H)	268	21.1
4 (urban)	1,426,000	24.0	3 (W)	97 (H)	340	8.2
5 (rural)	85,000	37.8	10 (O)	90 (H)	136	5.1
6 (urban)	175,000	26.9	80 (O)	20 (H)	108	2.9
7 (urban)	342,000	25.8	17 (O)	83 (H)	125	3.2
8 (rural)	285	n.a.	12 (W)	88 (H)	100	n.a.
9 (rural)	310	n.a.	n.a.	n.a.	40	n.a.
10 (urban)	141,000	4.2	23 (W)	77 (H)	143	0.6
Southeast Asia						
11 (rural)	614	5.2	0	100 (H)	n.a.	n.a.
12 (urban)	2,000,000	407.0	0	100 (H)	41/67[b]	16.7/27.3[b]
13 (urban)	2,000,000	496.0	0	100 (H)	36/61[b]	17.9/30.2[b]
14 (urban)	5,000,000	9.0	0	100 (H)	45/60[b]	0.4/0.5[b]
15 (urban)	5,000,000	582.0	0	100 (H)	31/62[b]	18.0/36.1[b]
16 (urban)	90,000	850.0	14 (S)	86 (H)	207	167.0[c]
17 (urban)	101,000	700.0	34 (S)	66 (H)	160	112.0[c]
18 (urban)	106,000	800.0	50 (S)	50 (H)	180	144.0[c]
Latin America						
19 (rural)	196	n.a.	0	100 (H)	n.a.	n.a.
20 (rural)	800	n.a.	0	100 (H)	53	n.a.
21 (suburban)	18,000	n.a.	n.a.	50 (H)	152	n.a.
22 (urban)	535,000	n.a.	n.a.	90 (H)	341	n.a.[d]
23 (rural)	12,000	30.0	0	100 (H)	n.a.	n.a.[d]
East and West Africa						
24 (urban)	20,000	n.a.	n.a.	n.a.	177[e]	n.a.
25 (urban)	114,000	n.a.	n.a.	n.a.	n.a.	n.a.
26 (urban)	250,000	n.a.	n.a.	n.a.	n.a.	n.a.
27 (urban)	500,000	n.a.	n.a.	n.a.	n.a.	n.a.
28 (urban)	500,000	n.a.	n.a.	n.a.	n.a.	n.a.
29 (urban)	650,000	n.a.	7 (O)	93 (S)	20	n.a.
North Africa						
30 (rural)	4,000	11.0	n.a.	95 (H)	50	0.6
31 (rural)	24,000	12.0	0	100 (S)	60	0.7
32 (urban)	250,000	107.0	0	100 (H)	70	7.5
33 (urban)	350,000	73.0	n.a.	97 (H)	100	7.3

n.a. Not available.
a. Percentages of population served by house connection (H), standpipe (S), vendor (V), well (W), or other service (O).
b. Paired values indicate liters per capita daily in dry/rainy season.
c. High values are for areas of heavy year-round afternoon rains and runoff.
d. Piped supplies available but not used because of water's disagreeable taste and color.
e. In more detail: 12 liters per capita daily for standpipe; 74 liters per capita daily for low-cost housing; 122 liters per capita daily for medium-cost housing; 434 liters per capita daily for high-cost housing.

ROECs

Another successful variation of the pit latrine is the ROEC (figure 2-1, no. 4). Its pit is completely displaced from the superstructure and connected to the squatting plate by a curved 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, thereby providing a possible site for fly breeding. The chute must therefore be cleaned regularly with a long-handled brush or a small amount of water. The advantages of the ROEC over the VIP latrine are that its pit can be larger and thus have a longer life (because the superstructure is displaced), the users (especially children) have no fear of falling into its pit, and it may be more acceptable in some societies because the excreta cannot be seen.

Table 2-2. *Sanitation Systems for Selected Study Communities*

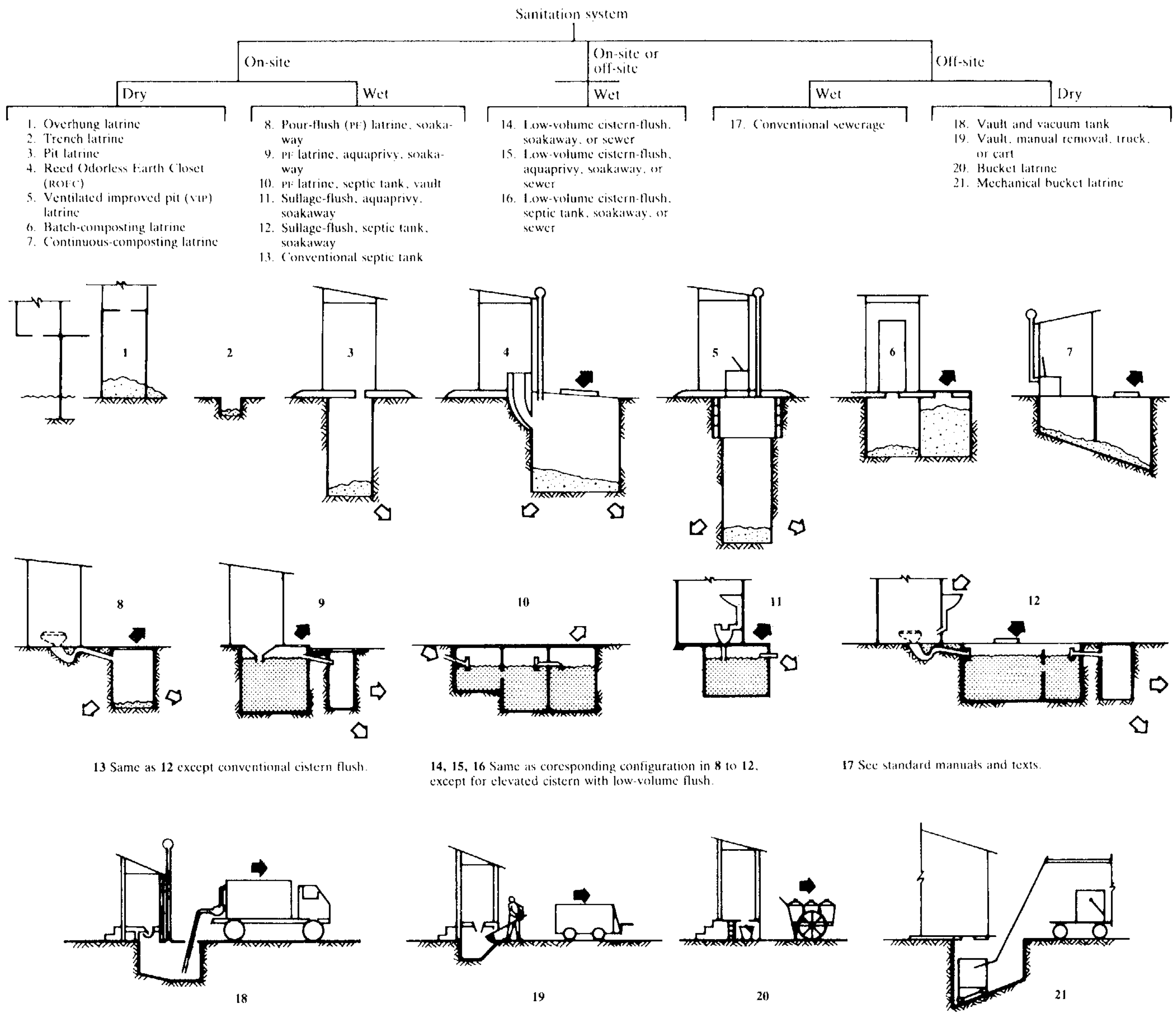
Community (see table 2-1 for population data)	*Sanitation systems present (*) or utilized (percent)*												
	Household systems											*Communal systems*	
	On-site								*Off-site*				
				Composting latrine									
	Pit latrine	ROEC	VIP	*Batch*	*Continuous*	PF	*Aqua-privy*	*Septic tank*	*Sewer*	*Vault*	*Bucket*	*Aqua-privy septic tank*	*Overhung latrine*
East Asia													
1								6	15	59			
2								10		81			
3	1							7	44	44			
4	1							15	41	41			
5								66		34			
6								57		29	14		
7	1							70			29		
8,9	100												
10								1		74			
Southeast Asia													
11	13												87
12	60					40							
13						7						93	
14	7					57							36
15	57					20						23	
16						1		46			49		4
17						34		56					10
18								66			15		19
Latin America													
19	30												
20	60												
21	50					15			29				
22	27								73				
23	35					14			9				
Africa													
24		*	*	*			*		*				
25	*	*	*	*	*			*	*			*	
26	*						*	*	*			*	
27	*						*						
28	*										*	*	
29	*										*	*	
30	98						1	1					
31	70										30		
32	84						1	1					
33	30						70						

Note: ROEC, Reed Odorless Earth Closet; VIP, ventilated improved pit latrine; PF, pour-flush toilet.

Pit latrines are most suitable in low- and medium-density areas (up to about 300 persons per hectare) where houses are single storied.[3] It is customary to place the latrine 3 to 5 meters from the house. Where appropriate measures for odor and fly control are taken (as in VIP latrines and ROECs), the latrine may be placed adjacent to the house. In sandy soil the pits may need to be partially lined to prevent collapse, and where the ground is rocky they may be difficult to dig. In areas that have a high water table or that are prone to flooding, the latrine may need to be raised partly above the ground. In addition, if nearby groundwater is used for drinking, pit latrines should not be placed within 10 meters or so of the well. If the soil is fissured, the pollution from the latrine will be more extensive, and this distance may need to be increased.

Where these environmental limitations do not apply, or where the disadvantages of other systems outweigh those of pit latrines, the VIP latrine and ROEC are suitable for replication. Their technical designs are good; they can easily be upgraded to PF toilets; their costs are low; and their potential for health benefits is

Figure 2-1. *Generic Classification of Sanitation Systems*



◊, Movement of liquids; ♦, movement of solids.

Source: The World Bank, *Water Supply and Waste Disposal*, Poverty and Basic Needs Series (Washington, D.C.: September 1980).

high. When introduced with an appropriate educational program for new users, they can be very effective at providing sanitation services affordable to the majority of people in rural and urban fringe areas.

PF toilets

There are two types of PF toilets. The first is a simple modification of the unimproved pit latrine in which the squatting plate is made with a 25-millimeter water seal. Approximately 1–2 liters of water (or sullage) are poured in by hand to flush the excreta into the pit.[4] This type of PF toilet is especially suitable wherever water is used for anal cleansing. The second type of PF toilet, which was observed in Indonesia and Colombia, has a completely displaced soakaway pit (figure 2-1, no. 8) that is connected to a PF bowl by a short length of 100-millimeter pipe. This type of PF toilet can be installed inside the house because it is free of odor and insect problems and its toilet fixture is displaced from the pit. When the pit is full, a new one is dug and the latrine is connected to it. Alternatively, and especially in densely populated areas, a vault may replace the pit and be emptied by vacuum cart (see figure 2-1, no. 18). The displaced PF toilet can therefore satisfy the aspiration for an "inside" toilet at low cost. In addition, as water use increases, the pit can be fitted with an outlet that connects to a drainfield or small-bore sewer system. This option is examined more fully in the discussion of sanitation sequencing (chapter 9, the section "Sanitation Sequences").

The environmental requirements for PF toilets are much the same as those for pit latrines. In addition, however, 3-6 liters per capita daily of water are required for flushing. Thus, in areas where water is carried from distant standpipes or surface sources, the pit latrine is probably a better choice until the community's level of water service is improved. The simple technical design, low operational requirements, and high potential for upgrading of PF toilets make them an attractive technology for widespread replication in many areas of the world. Their most severe limitations in practice are that users often do not use enough flushing water or that the toilets can become blocked by solid materials used for anal cleansing. For these reasons, an educational program for users should accompany the introduction of these facilities into a new area.

Composting toilets

There are two basic types of composting toilets: continuous and batch. The continuous composters (figure 2-1, no. 7) are developed from a Swedish design known as a "multrum." The composting pit, which is immediately below the squatting plate, has a sloping floor with inverted U- or V-shaped channels suspended above it to promote aerobic conditions in the chamber. Grass, ash, sawdust, or household refuse are added to the pit to attain the necessary carbon-nitrogen ratios for composting to occur. Moisture must be carefully controlled. The material slowly moves down the sloping floor and into a humus vault from which it must be removed regularly.

If the temperature in the composting chamber is raised by bacterial activity to above 60°C (degrees Celsius), all pathogens in the excreta will be destroyed. In the units observed in southern Africa, however, the temperatures inside were only slightly above ambient. In addition, continuous composters were extremely sensitive to the degree of user care: the humus had to be removed at the correct rate; organic matter had to be added in the correct quantities; and only a minimum of water could be added. Even if all these conditions are met, fresh excreta may occasionally slide into the humus pile and limit the compost's potential for safe reuse. The conclusion of this study, therefore, is that continuous composting toilets should not be recommended for use in either the urban or the rural tropics.

Double-vault composting (DVC) toilets (figure 2-1, no. 6) are the most common type of batch composting toilet. They have two adjacent vaults; one of these is used until it is about three-fourths full, at which point it is filled with earth and sealed and the other vault is used. Ash and organic matter are added to the vault before it is sealed to absorb odors and moisture. The composting process is anaerobic and requires several months, preferably a year, to make the compost pathogen-free and safe for use as a soil fertilizer or conditioner.

DVC toilets require some care by users to function properly and thus are harder to introduce than VIP latrines or PF toilets. They are unsuitable in areas where organic waste matter or grass are not easily available or where the users do not want to handle or use the composted humus. These factors tend to restrict their use to rural or periurban areas where users are likely to have gardens and access to grass for the composting process. Even here, unless there is a strong tradition of reusing excreta in agriculture, DVC toilets have no advantages—and in fact have major disadvantages—over the VIP latrine.

Aquaprivies

The conventional aquaprivy consists of a squatting plate above a small septic tank that discharges its effluent to an adjacent soakaway (figure 2-1, no. 9).

The squatting plate has an integral drop pipe that is submerged in the water of the tank to form a simple water seal. As long as the water level in the tank is properly maintained, odor and insect nuisance are avoided. In order to maintain the water level, the vault must be watertight and the user must flush sufficient water into the tank to replace any losses to evaporation. The tank normally requires desludging when it is about two-thirds full, usually every two to three years.

In practice, maintenance of the water seal has generally been a problem, either because users are unaware of its importance to the system or because they dislike carrying water into the toilet. If the seal is not maintained, there is intense odor release, and fly and mosquito problems abound. One African country banned the building of aquaprivies because of such problems. A variation on the conventional design, called the self-topping or sullage aquaprivy (figure 2-1, no. 11), was developed to overcome the problem of losing the water seal. A sink is located either inside the latrine or immediately adjacent to it and is connected to the tank so that sullage is regularly flushed into the aquaprivy. Because this additional water necessitates a larger soakage pit, sullage aquaprivies cannot be used in urban areas where the soil is not suitable for soakaways or where the housing density or water table is too high to permit subsurface infiltration for effluent disposal. In such cases it is possible to connect the aquaprivy tank to a small-bore sewer system, with eventual treatment of the sullage in a series of waste stabilization ponds. Desludging would still have to take place every two to three years.

If properly maintained, the conventional aquaprivy is a sound technical solution to excreta disposal. However, it has no technical advantage over the PF latrine, which is easier to build and maintain and costs less. In addition, with its more sophisticated water seal the PF latrine can be located inside the house and is more easily upgraded to a cistern-flush toilet (figure 2-1, no. 15). The only comparative advantage of the aquaprivy is that it is less easily blocked if solid cleansing materials are used or this material is thrown into the vault. Thus, except in cases in which users are unwilling to change such habits, the PF toilet should be preferred to the aquaprivy.

Septic tanks

The final household system to be discussed is the septic tank. The conventional septic tank (figure 2-1, nos. 12, 13) is a rectangular chamber, separated into two compartments sited just below ground level, that receives both excreta and sullage. During the one to three days of hydraulic retention time in the tank, the solids settle to the bottom where they are digested anaerobically just as in the aquaprivy. Although the digestion is reasonably good—about 50 percent reduction in biochemical oxygen demand (BOD)—enough sludge accumulates so that the tank must be desludged every one to five years. The effluent is usually disposed of in subsurface drainfields. In impermeable soils either evapotranspiration beds or upflow filters can be used, although there is little operational experience with either of these systems in developing countries.

Septic tank performance can be improved by various modifications—for example, the use of three (rather than two) compartments (figure 2-1, no. 10) or the addition of an anaerobic upflow filter. This latter modification requires further testing and evaluation before its widespread application can be recommended. The former is a well-known modification that is particularly useful for systems in which excreta and sullage are disposed of separately (as in PF latrines). By this modification excreta can be emptied into the first compartment and sullage into the second, with the effluent discharged from the third. This arrangement improves the settling efficiency of the wastes (including the separation and inactivation of pathogens), increases the soil absorption of the effluent, and permits the effluent's limited reuse.

Septic tanks are suitable only for houses that have both a water connection (necessary for the cistern-flush toilet) and sufficient land with permeable soil for effluent disposal. They are an important sanitation option because they can provide a very high level of service to those who can afford it in a given community, without necessitating the commitment of community funds for the construction of a sewerage system. Thus, as part of a sanitation package that can meet the needs of all the members in a given community, septic tanks have a widespread potential for replication because, with proper soil conditions, they permit satisfactory excreta disposal even for users of cistern-flush toilets (figure 2-1, no. 16).

Community Sanitation Systems

Bucket latrines, vault toilets, communal toilets, and sewerage systems for communities are examined in this section. All require both off-site facilities and a permanent organizational structure with full-time employees to operate successfully.

Bucket latrines

The traditional bucket latrine (figure 2-1, no. 20) consists of a squatting plate and a metal bucket, which is located in a small vault immediately below the squatting plate. The bucket 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.

During the course of this study, bucket latrine systems were observed in four countries in Africa and Southeast Asia. Problems of odor, insects, spillage, and generally unsanitary conditions at all collection and transfer points were ubiquitous. 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, covering collection buckets with tightly fitting lids, or mechanizing the system, as shown in figure 2-1, no. 21), it is still difficult in practice to ensure that the system is operated satisfactorily in developing countries. Even an improved bucket latrine system, therefore, is not one that can be recommended for new installations. Existing bucket latrines should be improved as a short-term measure and replaced by some other technology in the long term. In the high-density urban areas where bucket latrines are most often found, the most likely replacements for them include vault toilets and communal facilities.

Vault toilets

Vault toilets (figure 2-1, nos. 18 and 19), which are extensively used in East Asia, are similar to PF toilets, except that the vault is sealed and emptied by a vacuum pump at regular intervals of two to six weeks. As with the PF toilet, the vault may be built immediately below the squatting plate or displaced from it and connected to it by a short length of pipe. In the latter case, the vault may be shared by adjacent houses with some savings in construction and collection costs.

The vault itself need not be large. For example, for a family of six and with the vault being emptied every two weeks, the required vault volume is only 1.25 cubic meters, and about 0.6 cubic meters of night soil must be removed each time the vault is emptied. The collection cart or truck is equipped with vacuum tubing, which may be as long as 100 meters to permit access to houses distant from a road or path. Disposal of the collected night soil is usually by trenching or treatment works (see the section "Treatment Alternatives," below).

The vault toilet, emptied by either mechanically, electrically, or manually powered vacuum pump, is an extremely flexible form of sanitation for urban areas. Changes in urban land use are easily accommodated by redefining the routes for collection tanker trucks. Vaults are suitable for medium-rise buildings in which excreta can be flushed down a vertical pipe into a communal vault at, or below, ground level. From the user's point of view, there is little difference between vault and PF toilets; either can be built inside the house and no nuisance problems are likely. In addition, vault toilets require a minimal amount of water (3-6 liters per capita daily) and are suitable for any type of soil and at very high population densities. They can easily be upgraded into sewered PF toilets if at some stage it is desired to improve facilities for sullage disposal. Their main disadvantage is one shared by all community facilities: the need for an institutional capability to organize the collection service and operate the treatment facilities. The vault toilet systems for which quantitative data were obtained in this study were found in East Asia, where municipal institutions were well developed. Although the vault toilet system is technically sound, its widespread replication in other parts of the world requires that it be subjected to prototype testing on a scale large enough to involve institutional development.

Communal sanitation facilities

There are no unusual technical requirements for a communal toilet. It may be a PF toilet, an aquaprivy, a low-volume cistern-flush toilet, or some other type. If shower, laundry, and clothesline facilities are not available in the houses, they may be provided at the communal sanitation block. Such block facilities are normally designed with a capacity for twenty-five to fifty persons per toilet compartment and thirty to fifty persons per shower. The most frequent problems encountered in the communal facilities visited during this study were inadequate water supply (for PF toilets) and poor maintenance. From a mechanical viewpoint, communal facilities may be the only low-cost alternative for providing sanitation to people living in very dense cities with no room for individual facilities. The social and institutional commitment to provide for their maintenance, however, can be a serious constraint.

Sewerage

Conventional sewerage (see figure 9-5, *d*, in chapter 9) consists of a cistern-flush toilet connected to a network of underground sewers, which transport sewage and sullage to a treatment or disposal facility. The cistern-flush toilet is a water-seal squatting plate or pedestal unit from which excreta are flushed away by 10–20 liters of water stored in an automatically refilling cistern connected to the household water supply.

Sanitary sewers are usually made from concrete, asbestos cement, vitrified clay, or polyvinyl chloride (PVC) pipe. Sewers are designed for transport by gravity of a maximum flow of up to four times the average daily flow, and they need to be laid with a steep enough slope to provide for a "self-cleaning" velocity of about 1 meter per second to avoid blockages. A conventional sewer system will require a 225-millimeter pipe (the minimum recommended size) to be laid at 1 in 90 slope, whereas a sewered PF system with a vault to settle solids needs only a 100-millimeter pipe laid at a 1 in 200 gradient. Clearly, there is a considerable difference in excavation and pipe costs between the conventional and small-bore sewers, which will grow larger as the ground becomes rockier. Because small-bore sewers carry no solids, they also require fewer manholes than conventional sewers.

The main advantage of a conventional system is the high convenience to users it provides. The main technical constraints are its large water requirement, the difficulty of the excavation in very dense areas or in those with poor ground conditions (rocky soil, high water table, and the like), the problem of laying sewers in fairly straight lines through areas of "unplanned" housing without substantial demolition, the susceptibility of the pipe and joint materials to corrosion in hot climates, and the blockage and extra maintenance problems that may arise during the early years following construction of a sewer (when it is underused).[5] A further problem of conventional sewerage is the environmental hazard created by point discharge of such large volumes of wastewater. This problem is reduced with (expensive) tertiary treatment plants, but developed countries are now discovering that even elaborate treatment does not remove all of the environmental costs and consequences.

Over the past three decades numerous attempts have been made to design and build sewer systems around the world. The success rate has not been high. The majority of them have not gotten past the design stage because of the failure to take into account the financial constraints. Many of those built in developing countries have had very serious problems with consumer acceptance. Connection rates, even where mandated by law, have been very low. Of the eight sewer systems included in this study, three were operating close to capacity. One of those was in a Japanese city, and the other two were African systems built in the 1950s. Nevertheless, many cities have a central commercial area with high-rise buildings in which sewerage may be the most feasible solution. The lesson seems to be that the economies of scale in sewerage are illusory in areas where consumer acceptance is not assured. In developing a sanitation package for a city, planners should consider sewerage only for those areas in which it is clearly the most appropriate sanitation system for social and economic, as well as technical, reasons.

Factors Affecting Choice of Technology

Before the discussion proceeds to treatment, reclamation, and disposal alternatives, a summary of the major technical and environmental factors that affect the choice of sanitation technology may be useful.

Physical environment

A group of maps is provided in this chapter to illustrate the range of constraints imposed by the global distribution of environmental variables (maps 1 through 11) and some of the common tropical sanitation-related diseases (maps 12 through 19).

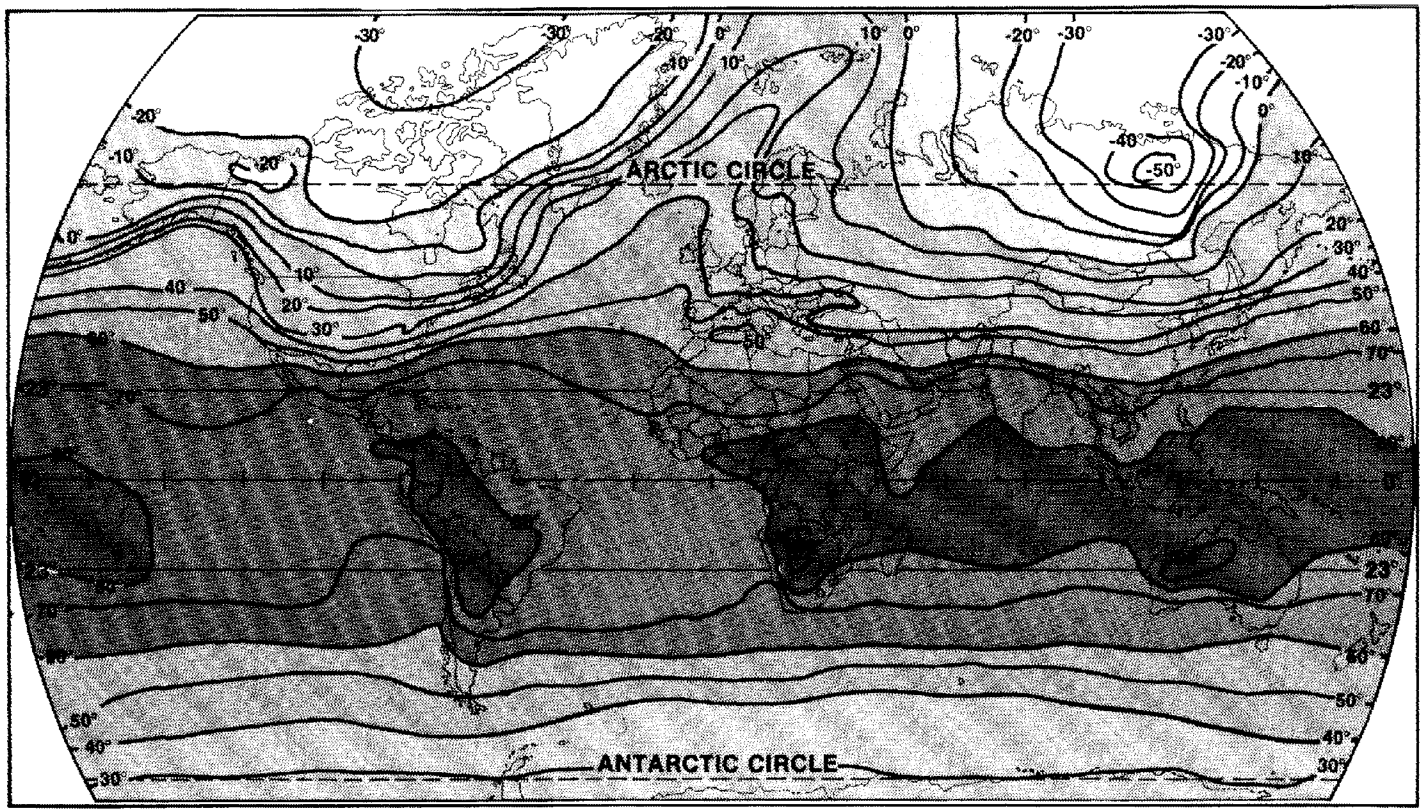
Information on the natural physical environment of an area will often permit the exclusion of certain options. Winter temperatures (maps 1 and 2) affect the performance of waste treatment ponds, digesters, and biogas units because each decrease of about 10°C or 18°F (degrees Fahrenheit) causes a decrease in biochemical reaction rates by one-half. The distribution of precipitation (map 3) indicates the general levels of flooding, runoff, water table, and plant growth. The climate diagrams (maps 4 through 6) show details of temperature and precipitation for specific locations considered in the present research. Horizontal scales on the inset charts are in months (January to December in the northern hemisphere and July to June in the southern hemisphere); in each case summer is in the middle of the scale. Aridity index maps (maps 7 through 9) show the ratios of potential evaporation to precipitation and indicate climatic zones, particularly those subject to desertification, in which the recovery of water, fertilizer, and energy from wastes is most important. Soils and potential productivity are shown in maps 10 and 11; the former reflects long-term effects of climate, and the latter is a measure of land or aquatic plant growth. Soil and weather allow for higher productivity in the tropics, where rapid cycling of material through the biosphere is a major element in the efficiencies of waste treatment ponds.

Distributions of most of the diseases shown in maps 12 through 19 indicate the environmental influence on health in the tropics. The limits are based on reported cases, and the absence of cases may be because of the absence of the disease itself or of specialists who can recognize it.[6]

In contrast to the regional or global environmental influences, local changes in land use are often the

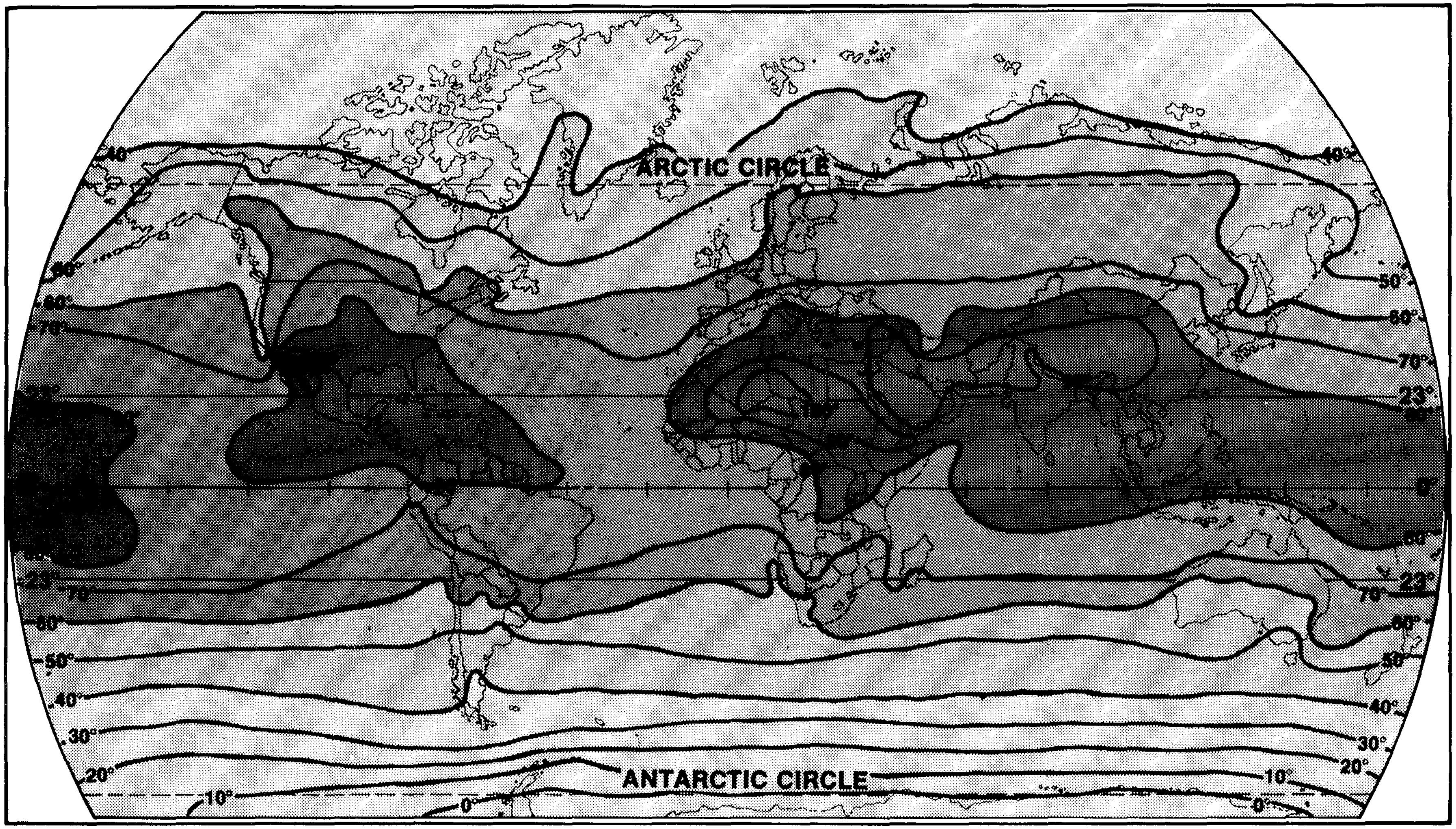
(Text continues on page 39.)

MAP 1. **Average January Temperature**
(degrees Farenheit)



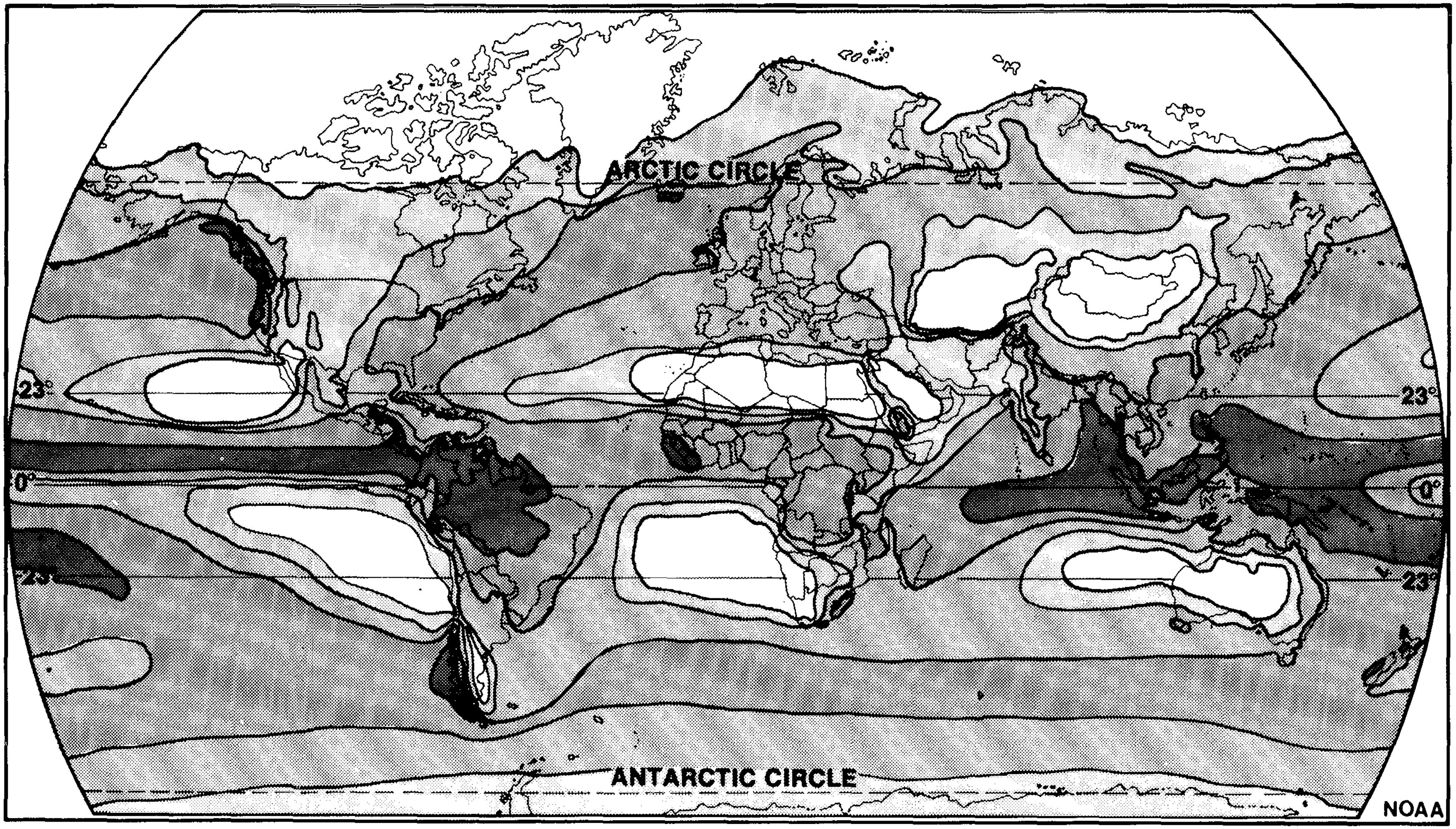
Source: U.S. National Oceanic and Atmospheric Administration (NOAA) (Boulder, Colo.); from U.S. Department of Commerce records.

MAP 2. **Average July Temperature**
(degrees Fahrenheit)



Source: Same as for map 1.

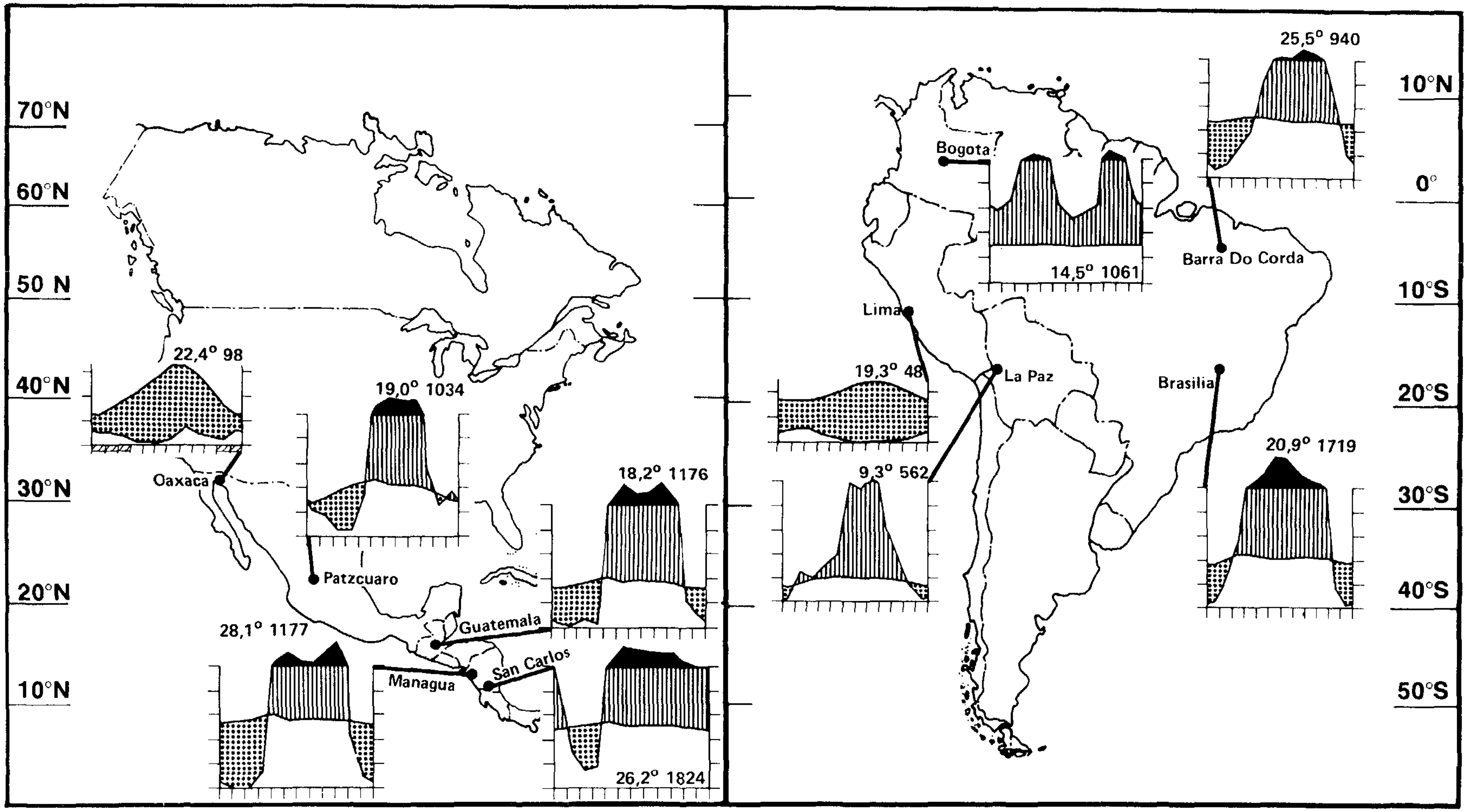
MAP 3. **Generalized Annual Global Precipitation**
(millimeters)



<250; 250–500; 500–1,000; 1,000–2,000; >2,000.

Source: Same as for map 1.

MAP 4. **Temperature and Precipitation, Central and South America**
(degrees Celsius; millimeters)

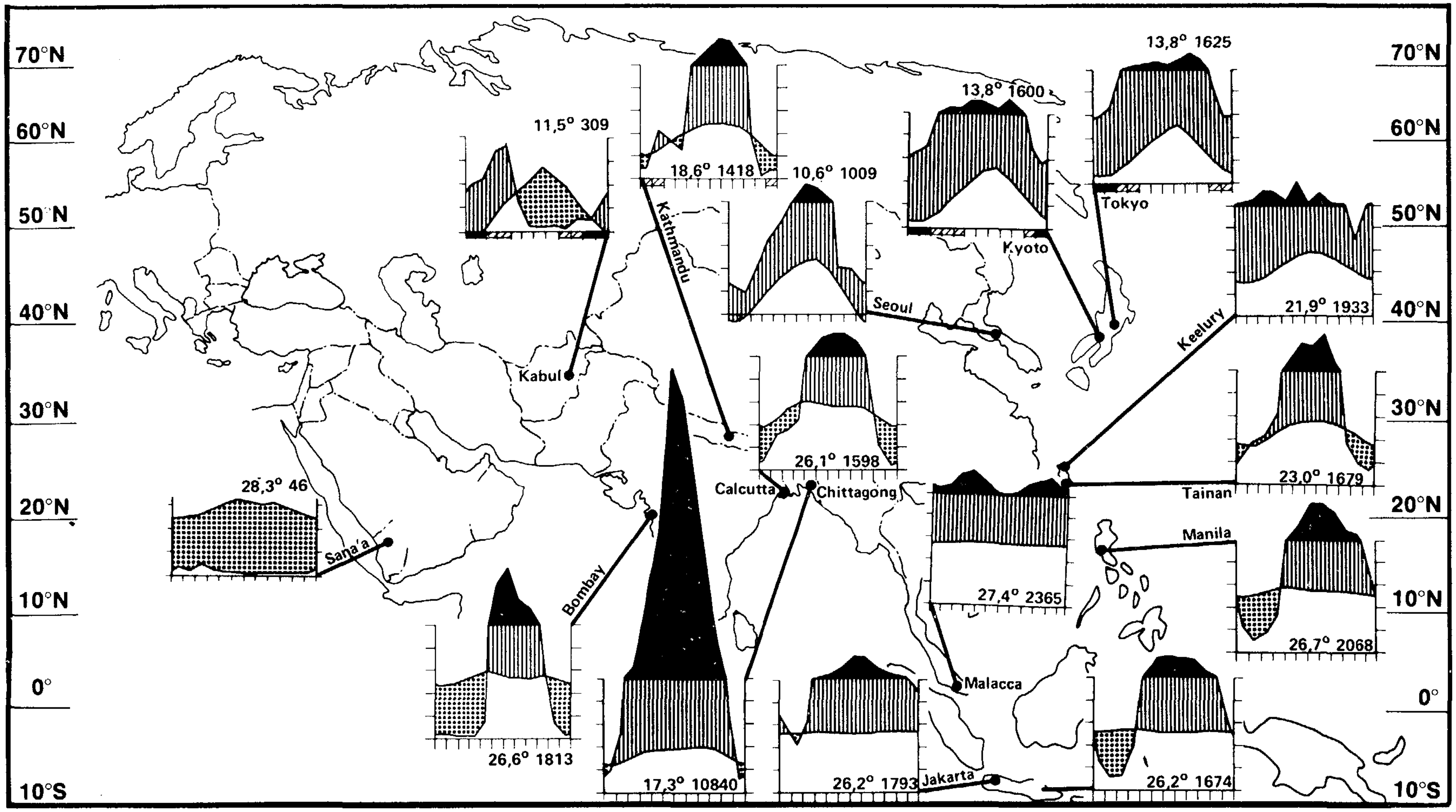


dry season; wet season; wet season, precipitation more than 100 millimeters.

Numbers on inset charts indicate, in order, average annual temperature (°C) and precipitation (millimeters). Horizontal scales are in months—January through December in the northern hemisphere, July through June in the southern hemisphere—and showperiods of freezing (solid bars) and frost (hatched bars). Left-hand vertical scales indicate temperatures above O°C in 10° intervals; right-hand vertical scales indicate 0–100 millimeters of precipitation in 20-millimeter intervals and 100 millimeters of precipitation in 100-millimeter intervals.

Sources: Adapted from H. Walter and H. Lieth, *Klimadiagram Weltatlas* (Jena: VEB Gustav Fischer Verlag, 1960) and H. Walter, E. Harnickell, and D. Mueller-Dombois, *Climate-diagram Maps* (Berlin: Springer-Verlag, 1975). © 1960 Gustav Fischer Verlag and 1975 Springer-Verlag, respectively. Used by permission.

MAP 5. **Temperature and Precipitation, Asia**
(degrees Celsius; millimeters)

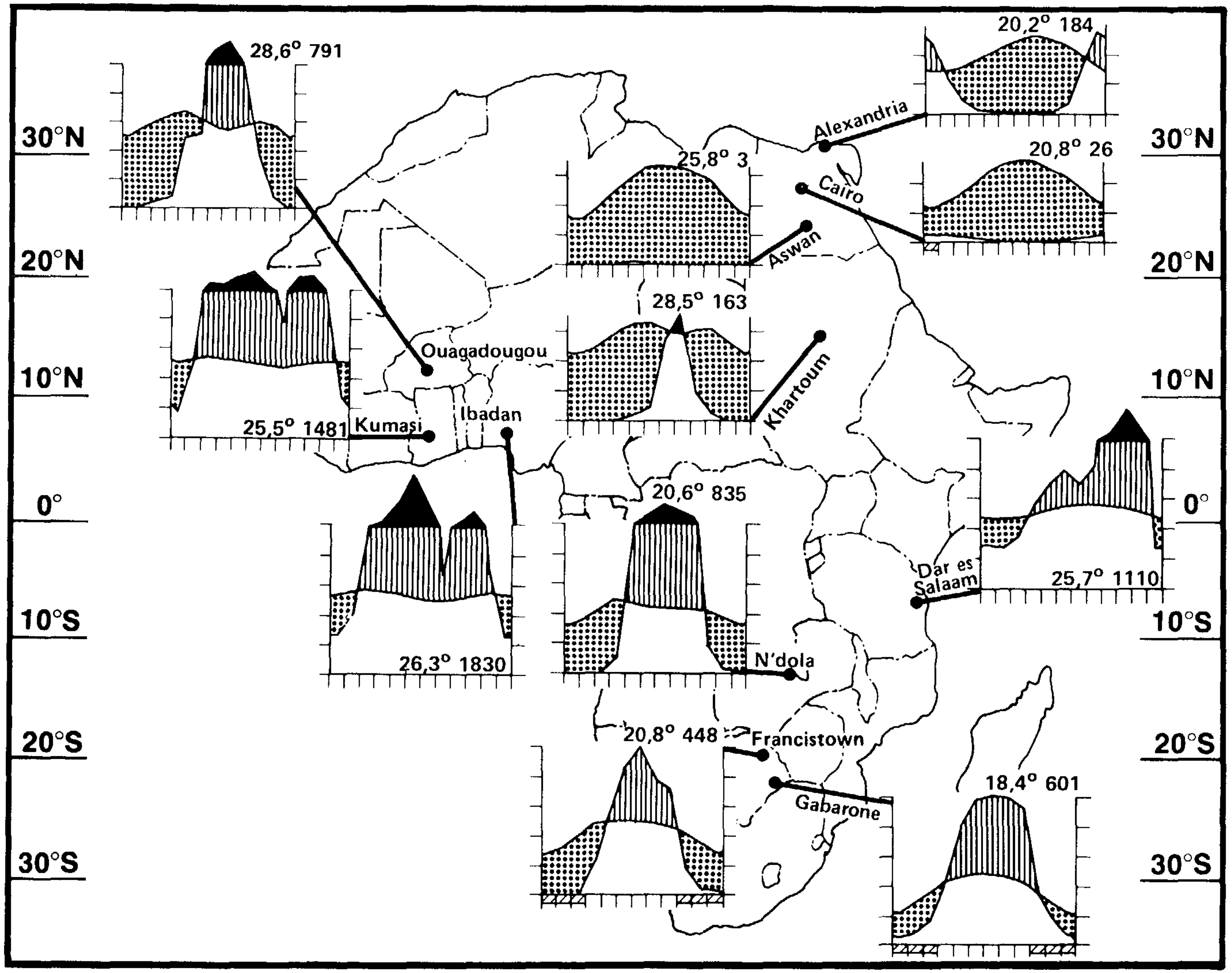


dry season; wet season; wet season, precipitation more than 100 millimeters.

See map 4 for explanation of inset charts.

Sources: Same as for map 4.

MAP 6. **Temperature and Precipitation, Africa**
(degrees Celsius; millimeters)

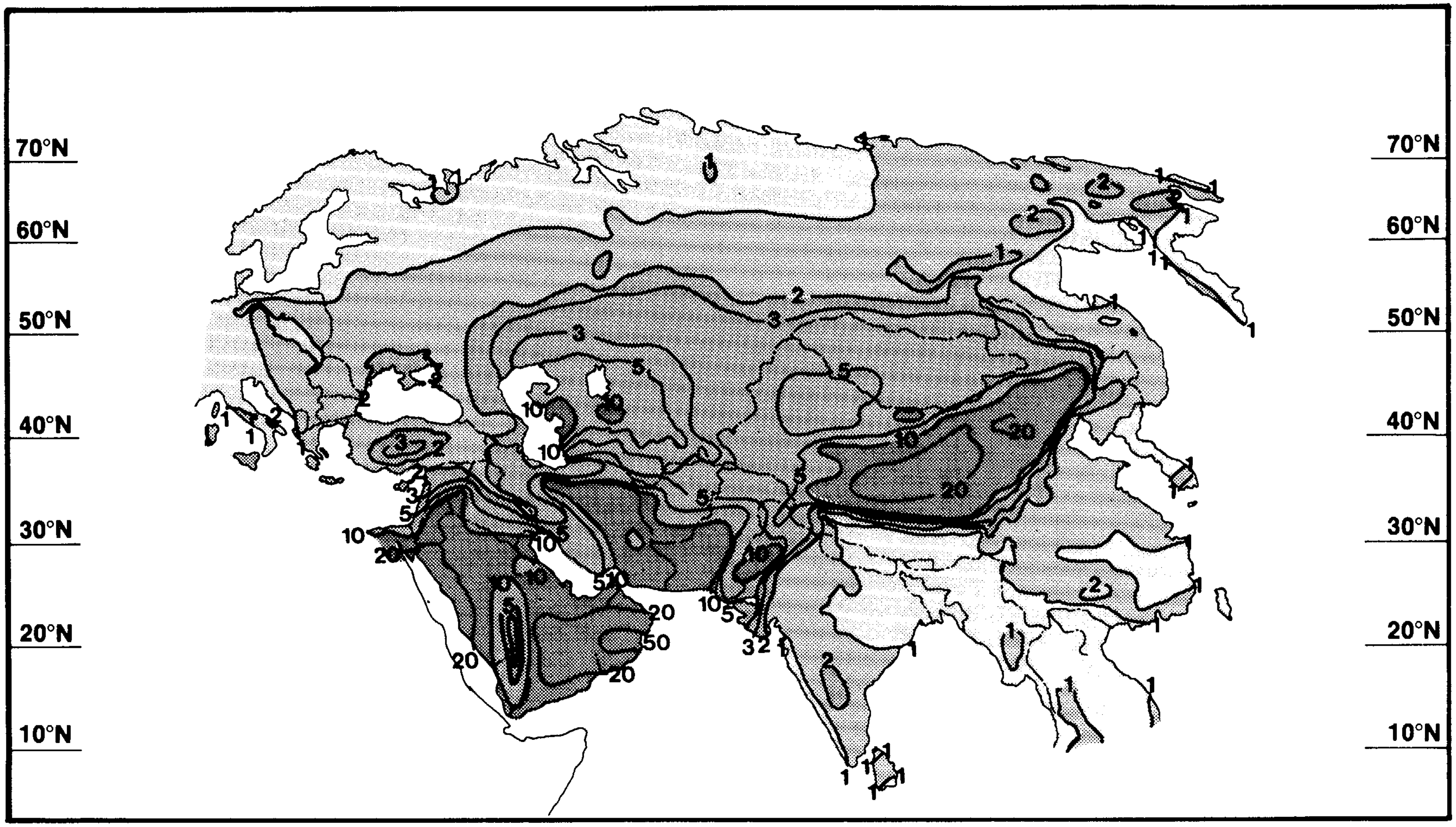


dry season; wet season; wet season, precipitation more than 100 millimeters.

See map 4 for explanation of inset charts.

Sources: Same as for map 4.

MAP 7. **Aridity Index for Asia**

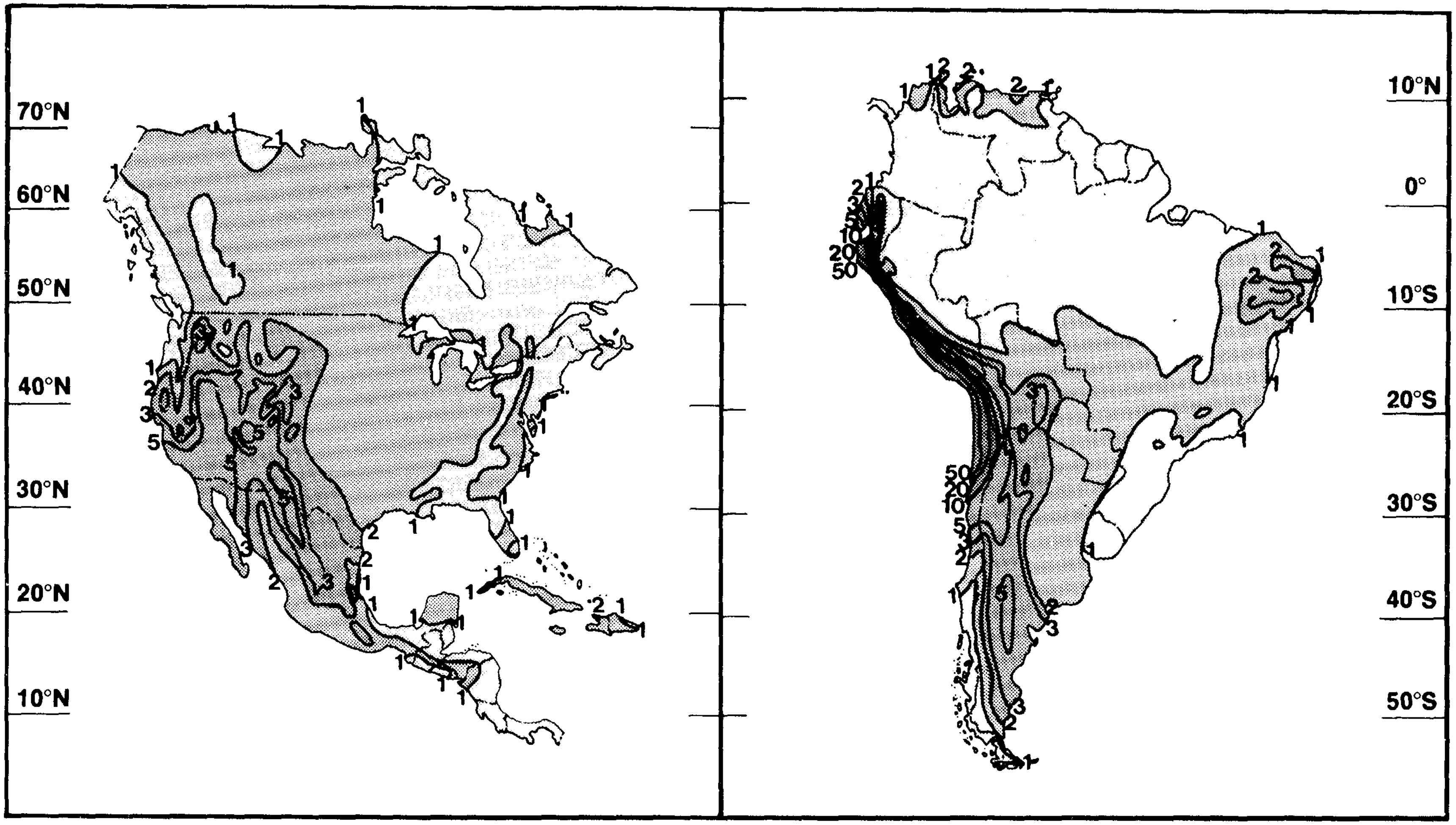


humid; savannah or steppe; desertification; desert.

Isopleths show ratios of potential evaporation to average precipitation. Ratios are calculated by dividing mean annual net radiation by product of mean annual precipitation and latent heat of vaporization.

Sources: After Budyko-Lettau. Adapted from D. Henning, *Atlas of Climate Aridity Indices* (unpublished) and F. K. Hare, *Climate and Desertification* (Toronto: University of Toronto Press, 1976). © 1976 University of Toronto Press. Used by permission.

MAP 8. **Aridity Index for North and South America**

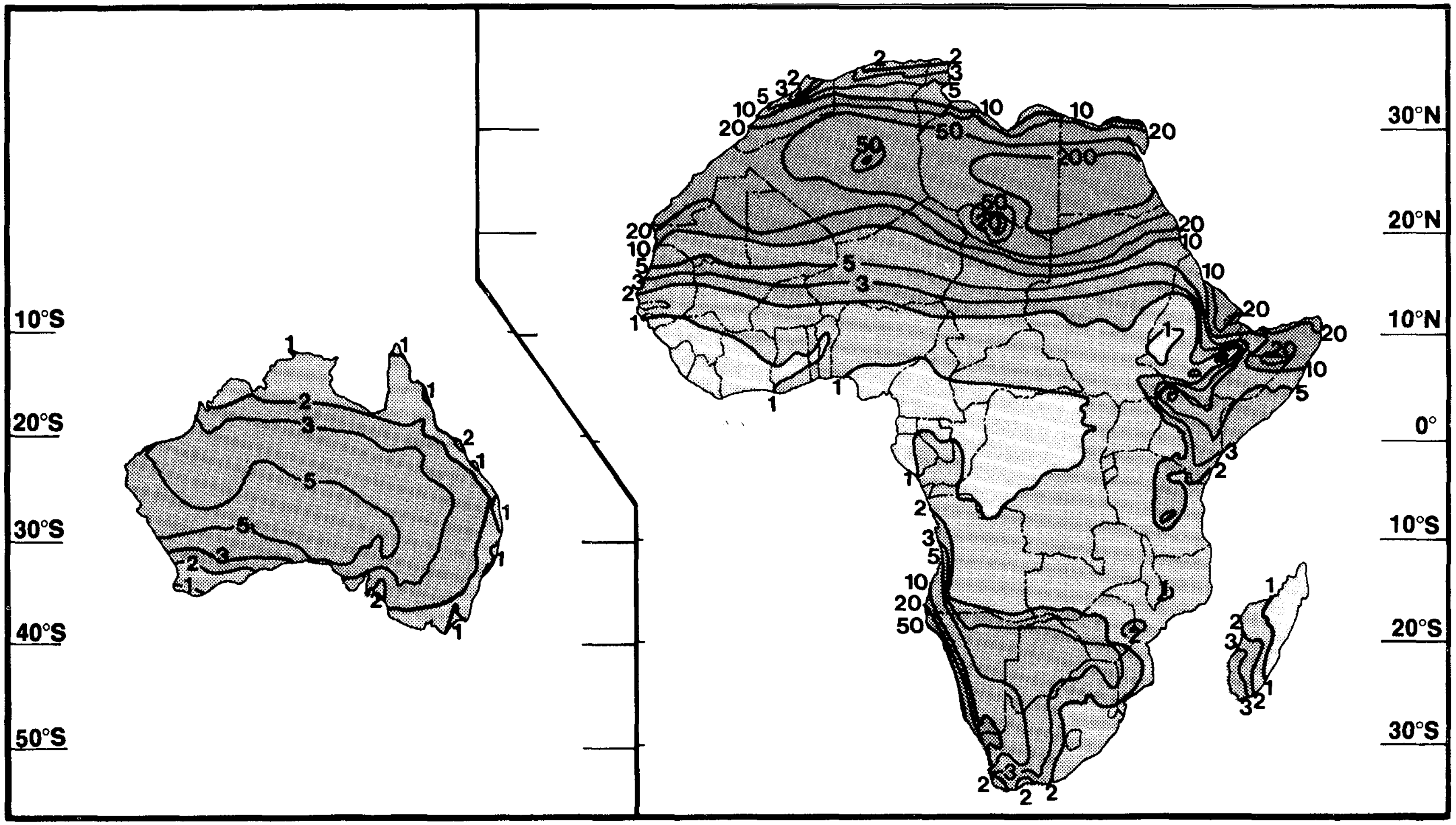


humid; savannah or steppe; desertification; desert.

See also note to map 7.

Sources: Same as for map 7.

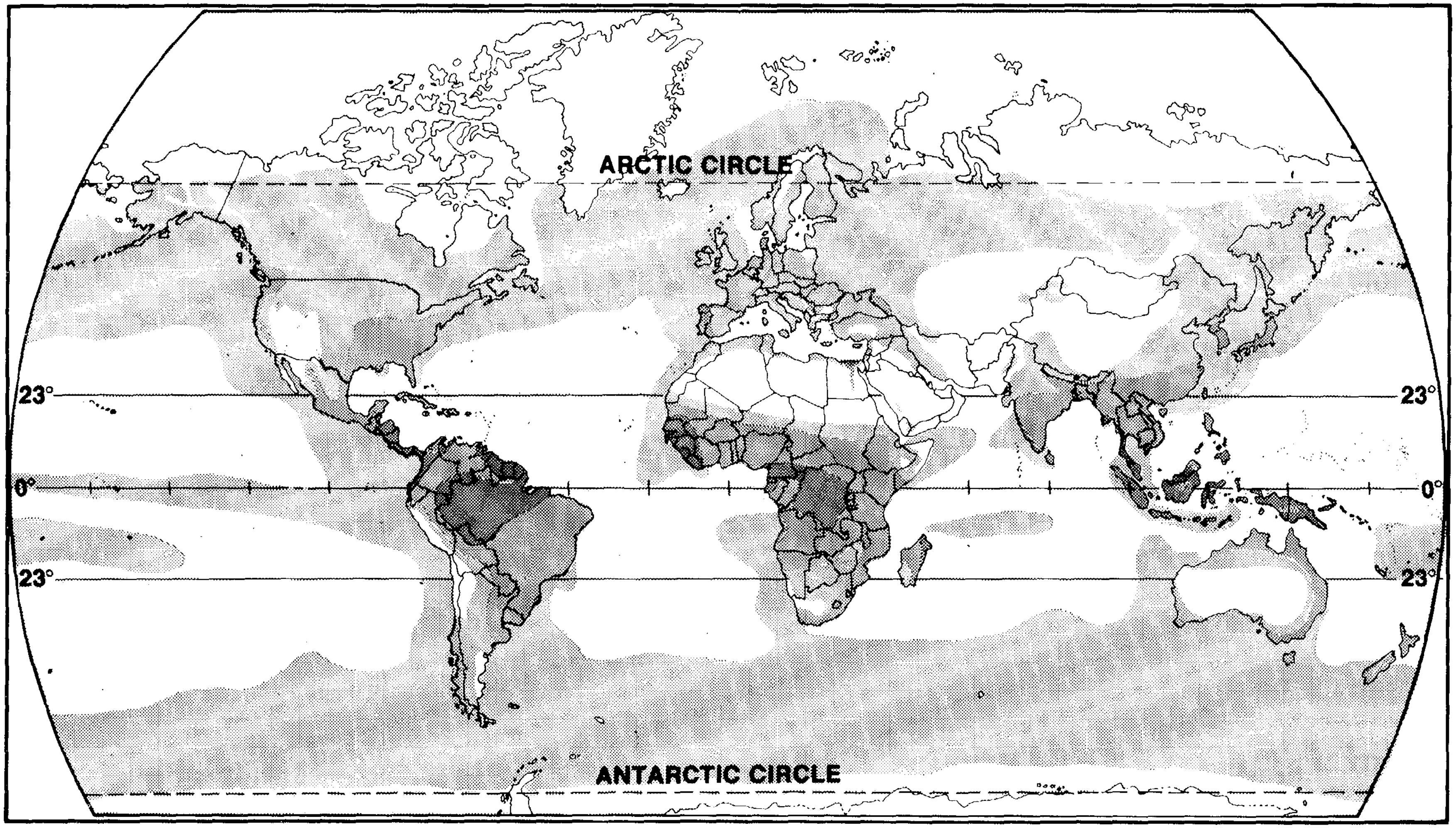
MAP 9. **Aridity Index for Africa and Australia**



humid; savannah or steppe; desertification; desert.

See also note to map 7.
Sources: Same as for map 7.

MAP 10. **Potential Productivity by Annual Carbon Fixation**
(grams of carbon fixed per square meter annually)

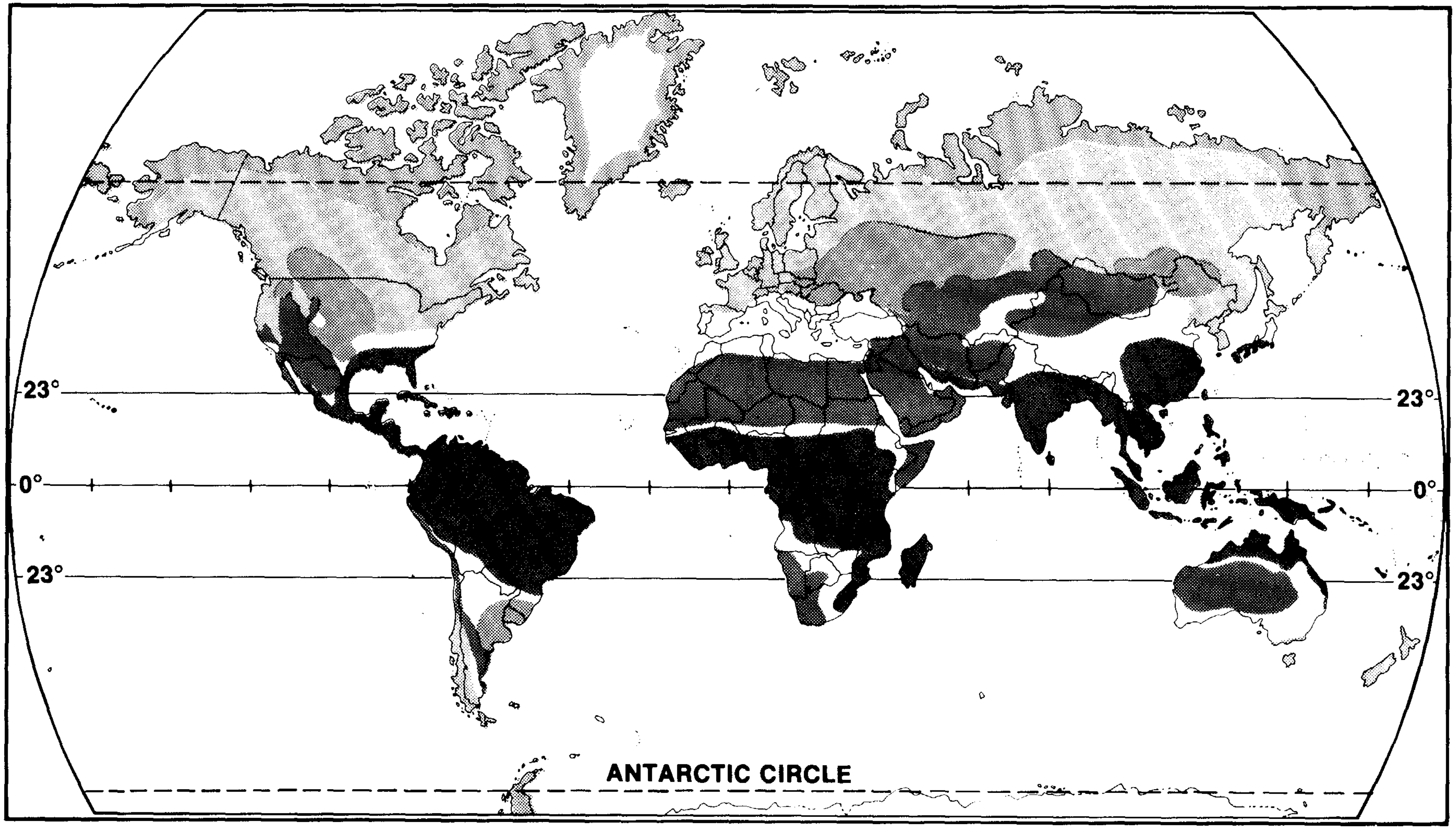


>800; 400–800; 100–400; 0–100; oceans 0–200; oceans >200.

Potential productivity, a measurement of the amount of plant material produced annually, is the response of plants (and the animals that eat them) to the combination of total annual sunlight, temperature, and precipitation (see maps 1–3). High values indicate rapid recycling of nutrients, potentially rapid growth of living matter, high year-round efficiency of sewage oxidation ponds, and favorable conditions for fish culture in ponds enriched with night soil or sewage. Low values indicate environmental constraints upon these processes.

Source: Adapted from H. Lieth, "Modeling the Primary Productivity of the World," in H. Lieth and R. H. Whittaker (eds.), *Primary Productivity of the Biosphere* (Berlin: Springer-Verlag, 1975). © 1975 Springer-Verlag. Used by permission.

MAP 11. **Generalized Distribution of Soil Types and Processes**

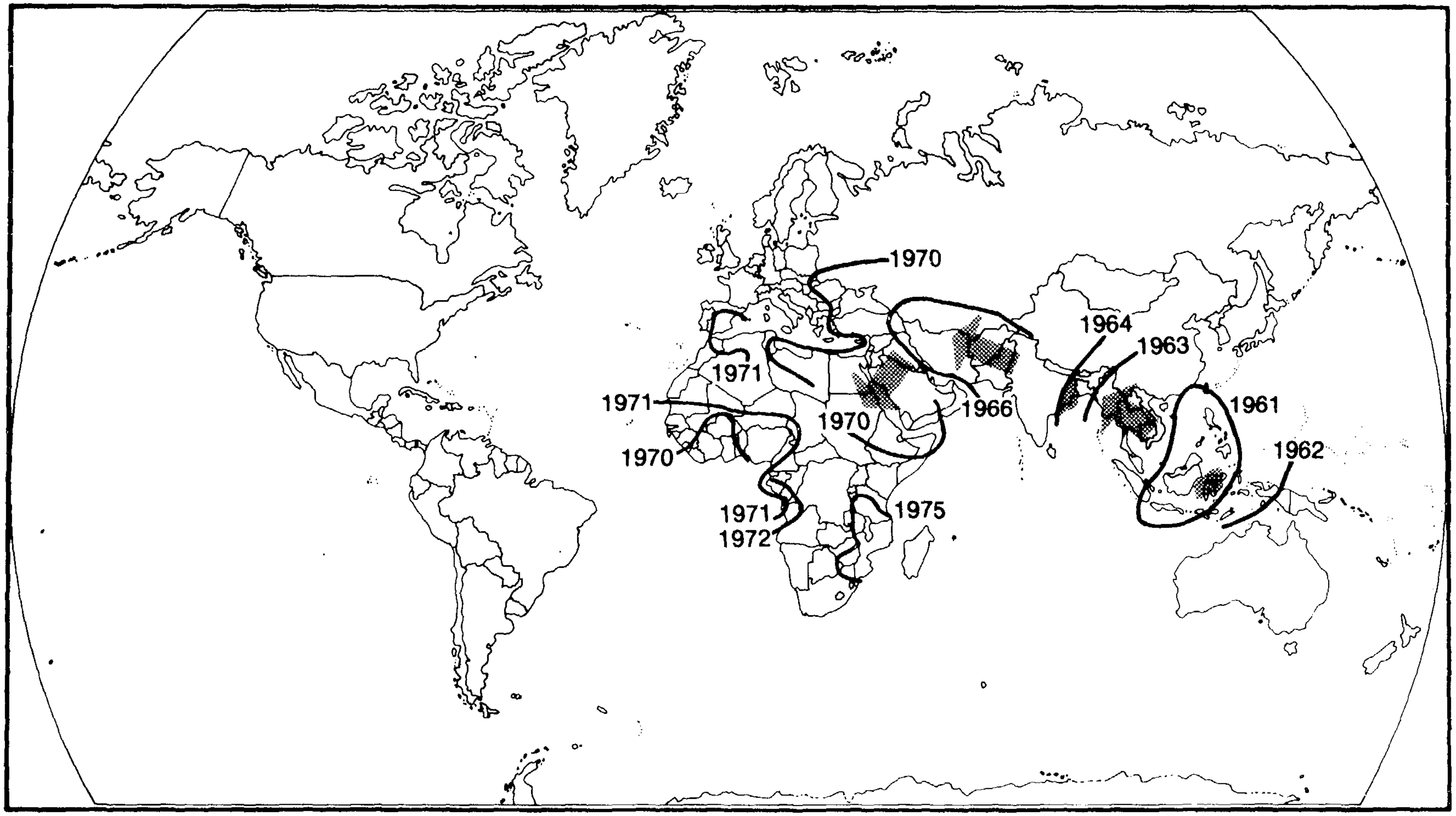


laterization; salinization; calcification; gleization; podzolization.

Both plants and soils are affected by climate, and regional variations occur not only in plant productivity (map 10) but also in soils and the processes governing their formation. Laterites are clayey soils with high contents of (red) iron oxide and aluminum oxide whose nutrients have been largely leached away by rains. Saline soils are created when evaporation from soil or plant surfaces exceeds water supply, causing dissolved salts to accumulate in the soil. Caliche is a layer, often discontinuous, of calcium and magnesium carbonates at about the depth to which water percolates. Gley is a blue- or olive-gray layer of clay under the surface of certain water-logged soils in cold climates. Podzols are leached, acidic soils formed in temperate-to-cold, moist climates under coniferous or mixed forest or heath. Combinations of soil types and potential productivity constitute constraints within which waste reclamation activities can function.

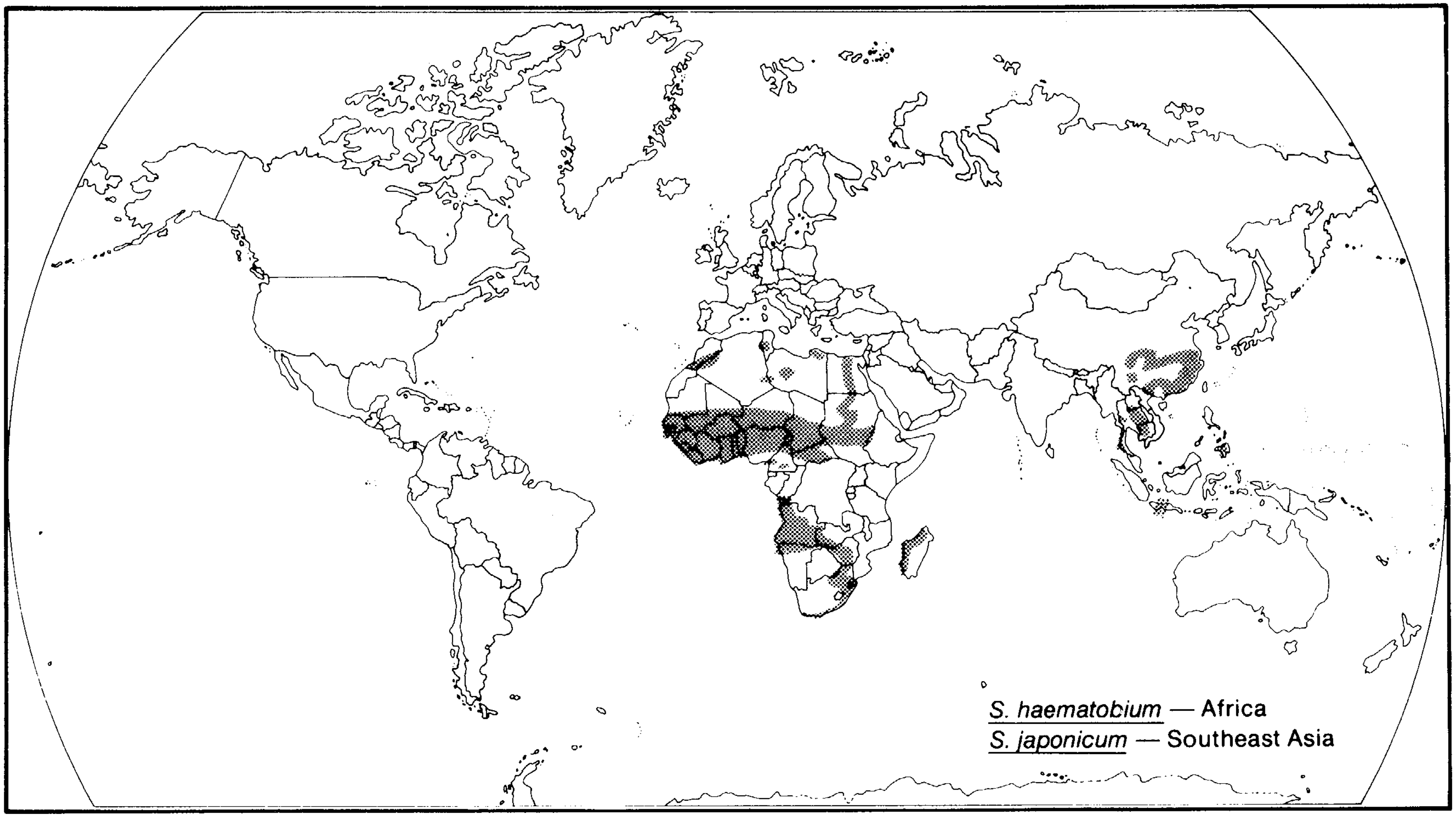
Source: NOAA, Environmental Research Laboratories (Boulder, Colo.).

MAP 12. **Global Spread of Cholera, Pandemic El Tor Variety from Celebes to Africa, 1961 to 1975**



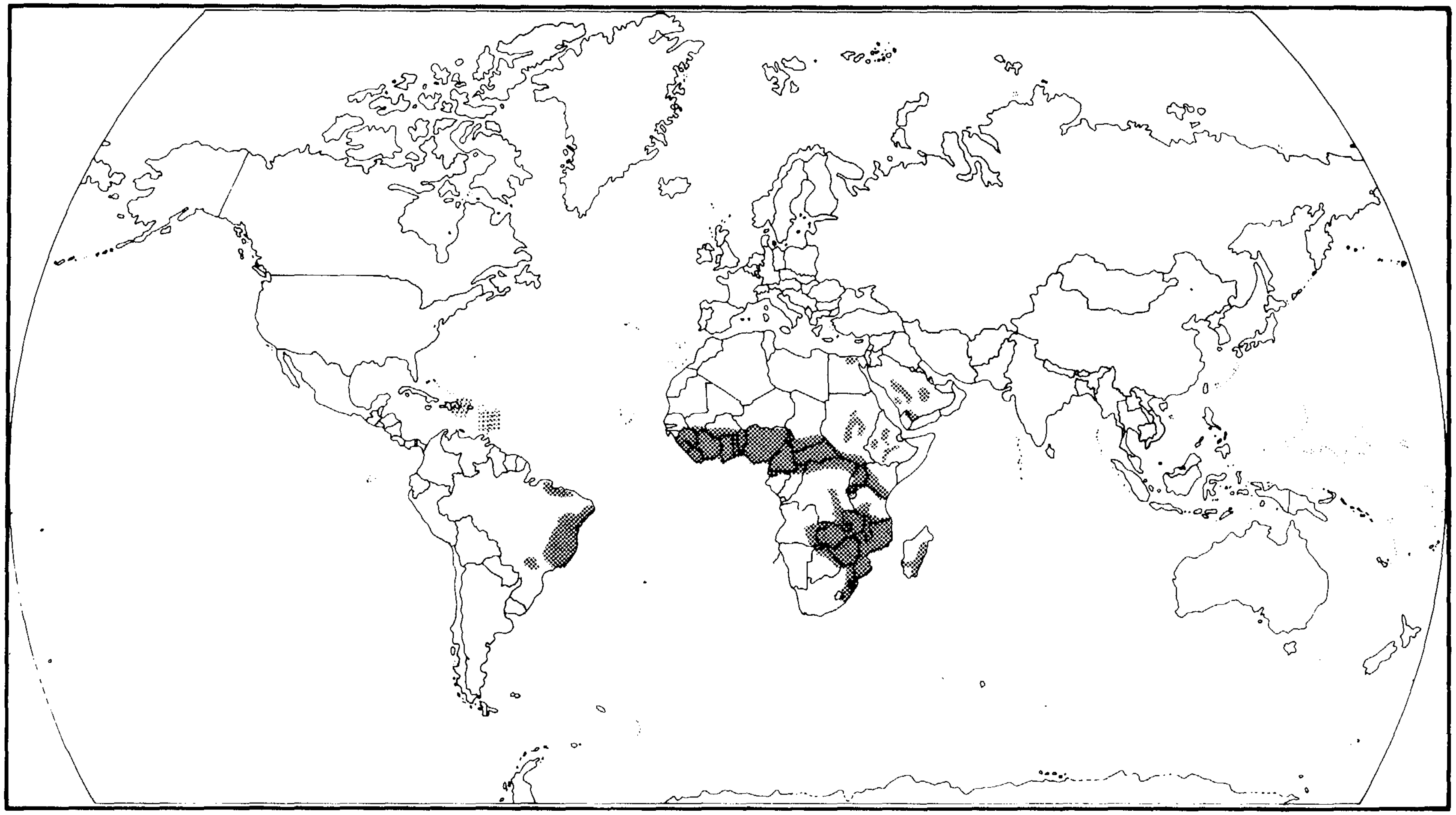
Source: Adapted from Richard G. Feachem and others, *Sanitation and Disease: Health Aspects of Excreta and Wastewater Management*, World Bank Studies in Water Supply and Sanitation, no. 3 (Baltimore: Johns Hopkins University Press, forthcoming).

MAP 13. **Known Geographical Distribution of Schistosoma haematobium and S. japonicum**



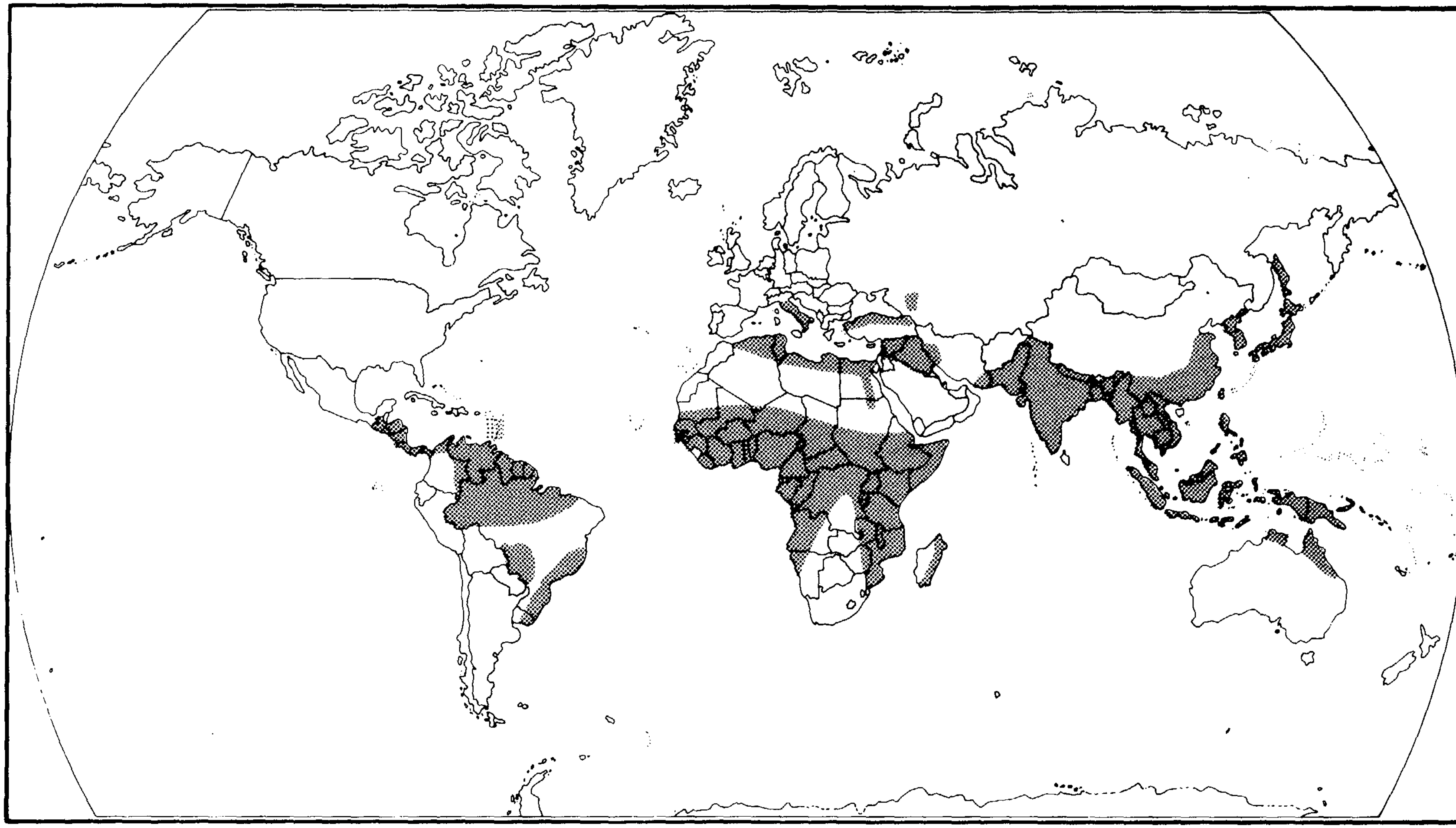
Source: Same as for map 12.

MAP 14. **Known Geographical Distribution of Schistosoma mansoni**



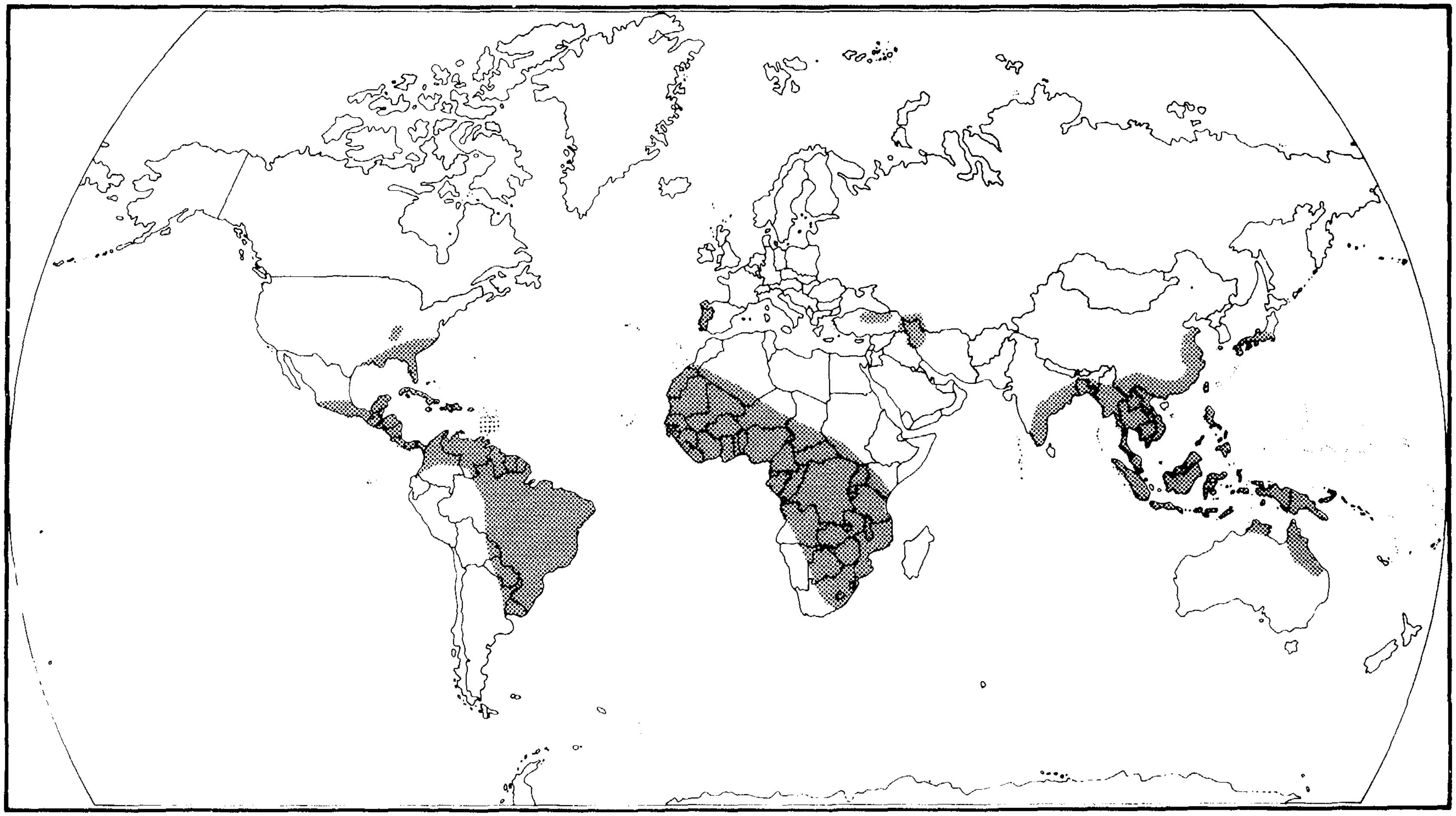
Source: Same as for map 12.

MAP 15. **Known Geographical Distribution of Ancylostoma duodenale**



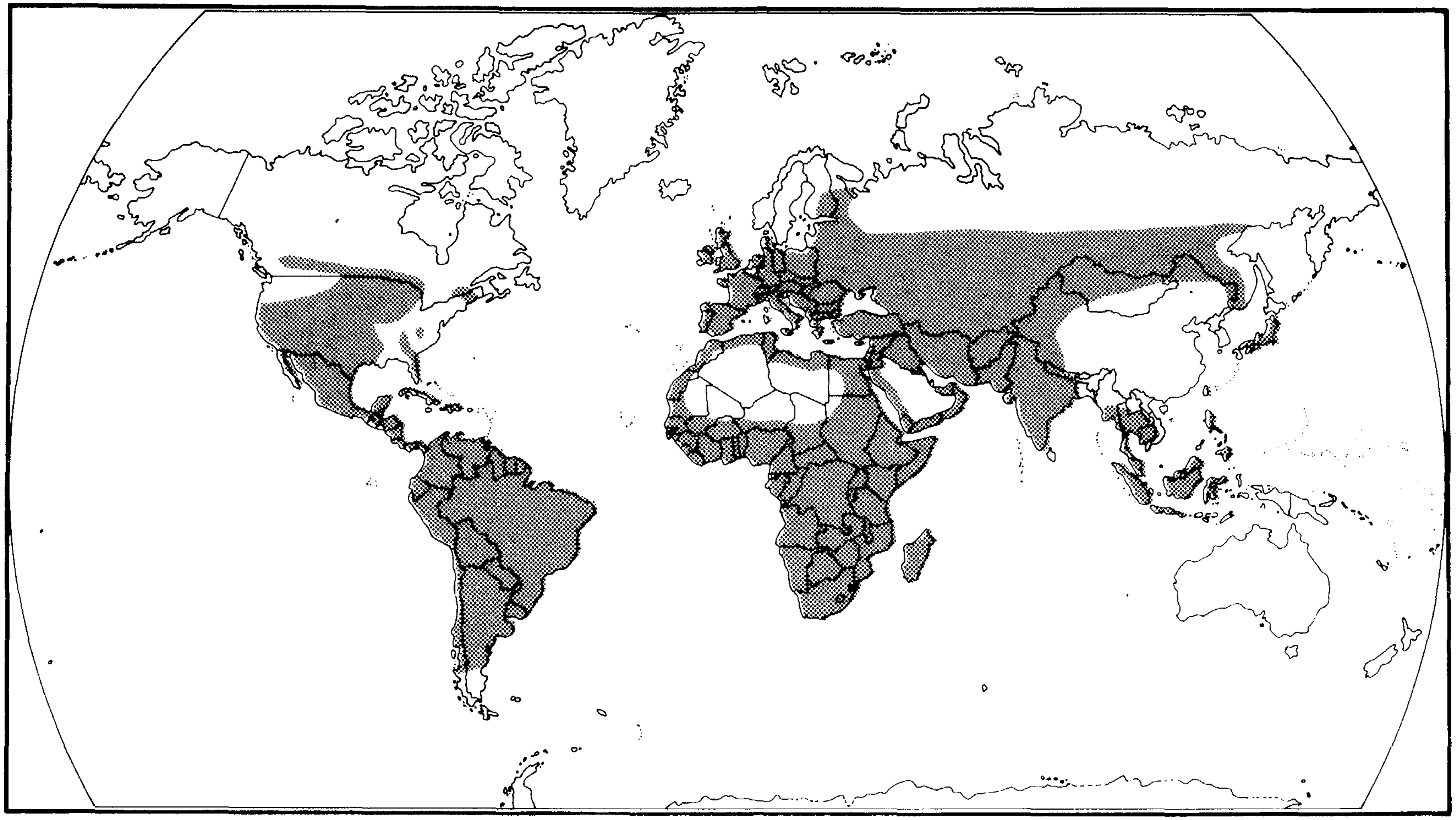
Source: Same as for map 12.

MAP 16. **Known Geographical Distribution of Necator americanus**



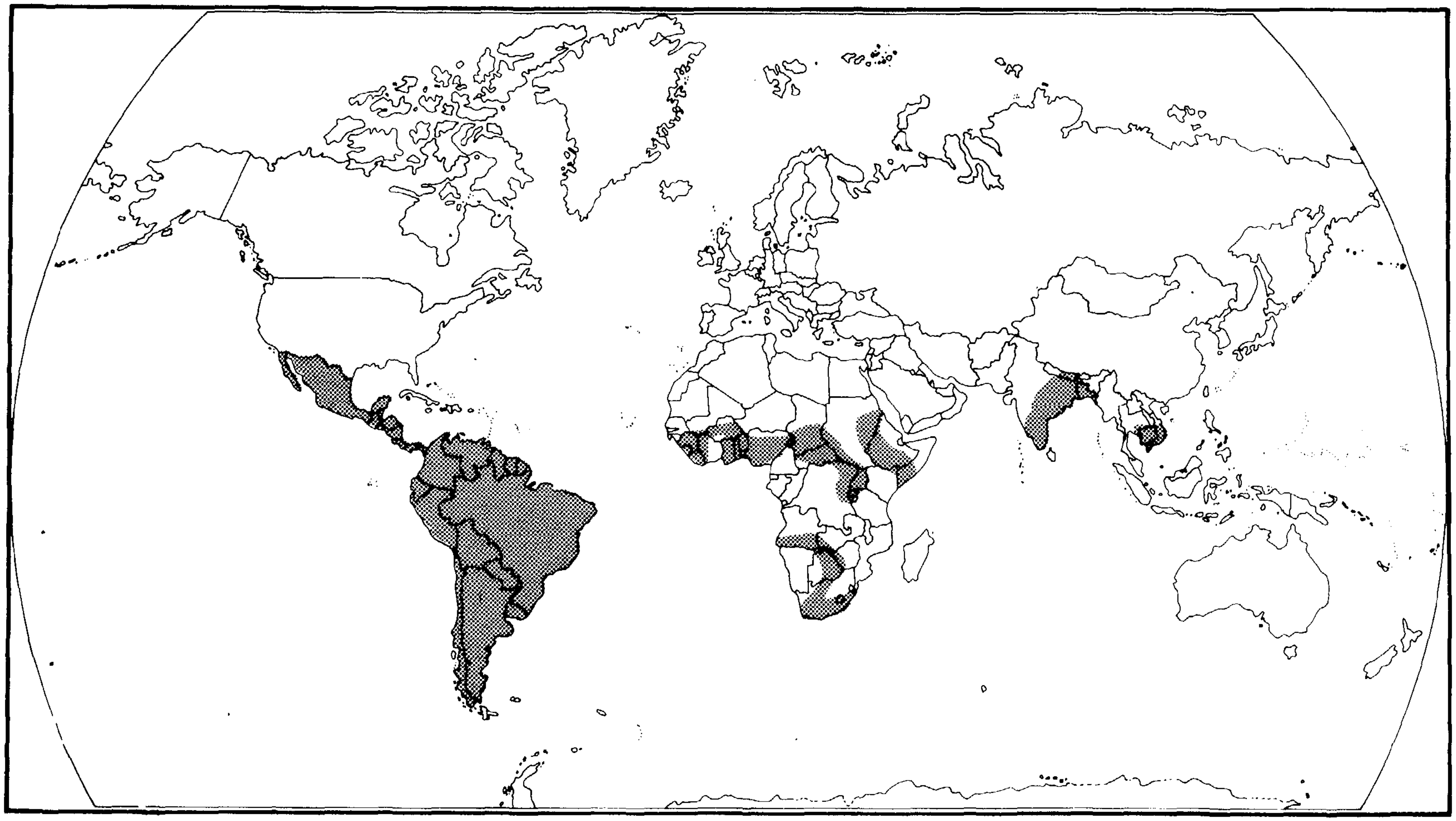
Source: Same as for map 12.

MAP 17. **Known Geographic Distribution of Taenia saginata (Beef Tapeworm)**



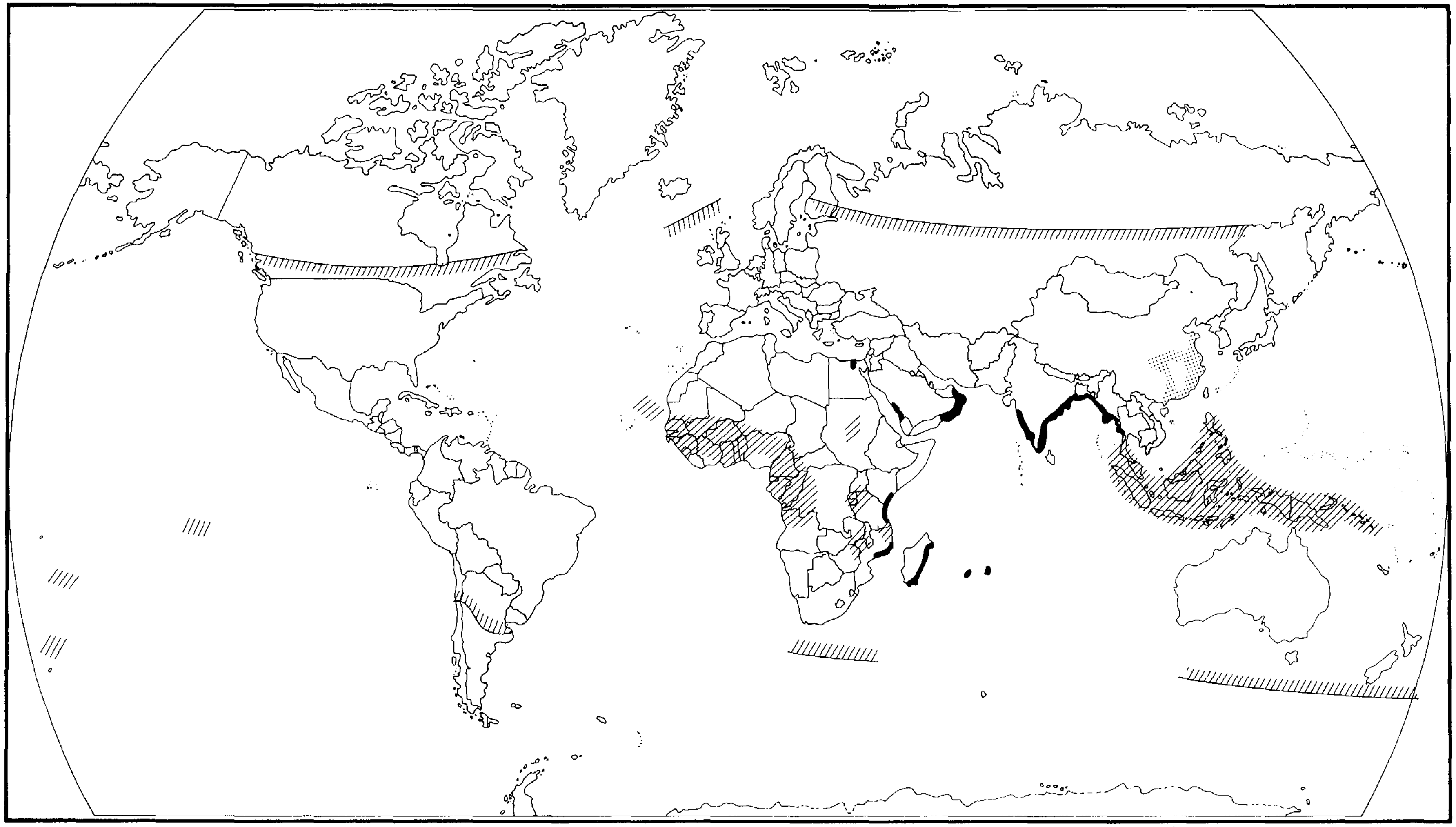
Source: Same as for map 12.

MAP 18. **Known Geographical Distribution of Taenia solium (Pork Tapeworm)**



Source: Same as for map 12.

MAP 19. **Known Geographical Distribution of Culex pipiens**

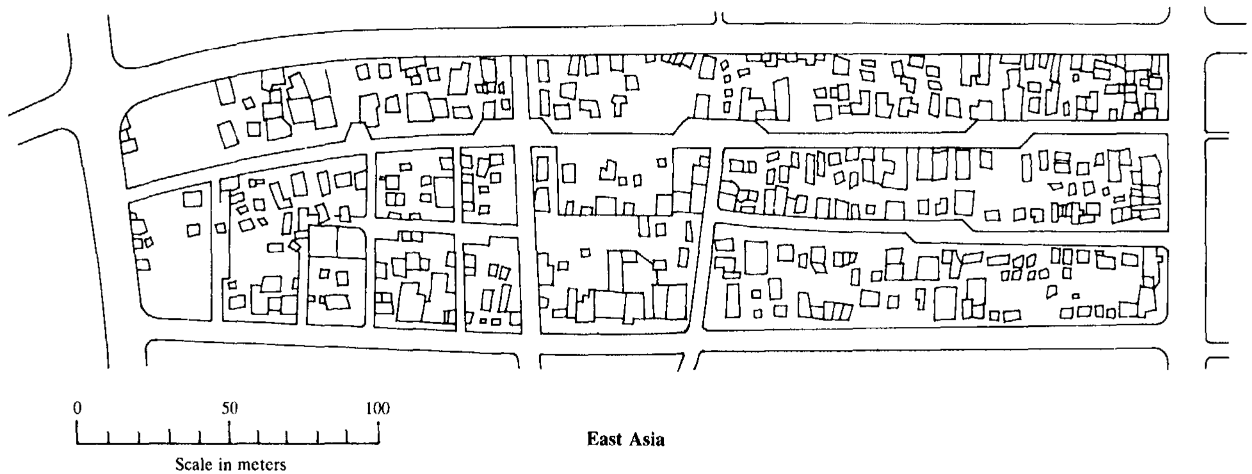


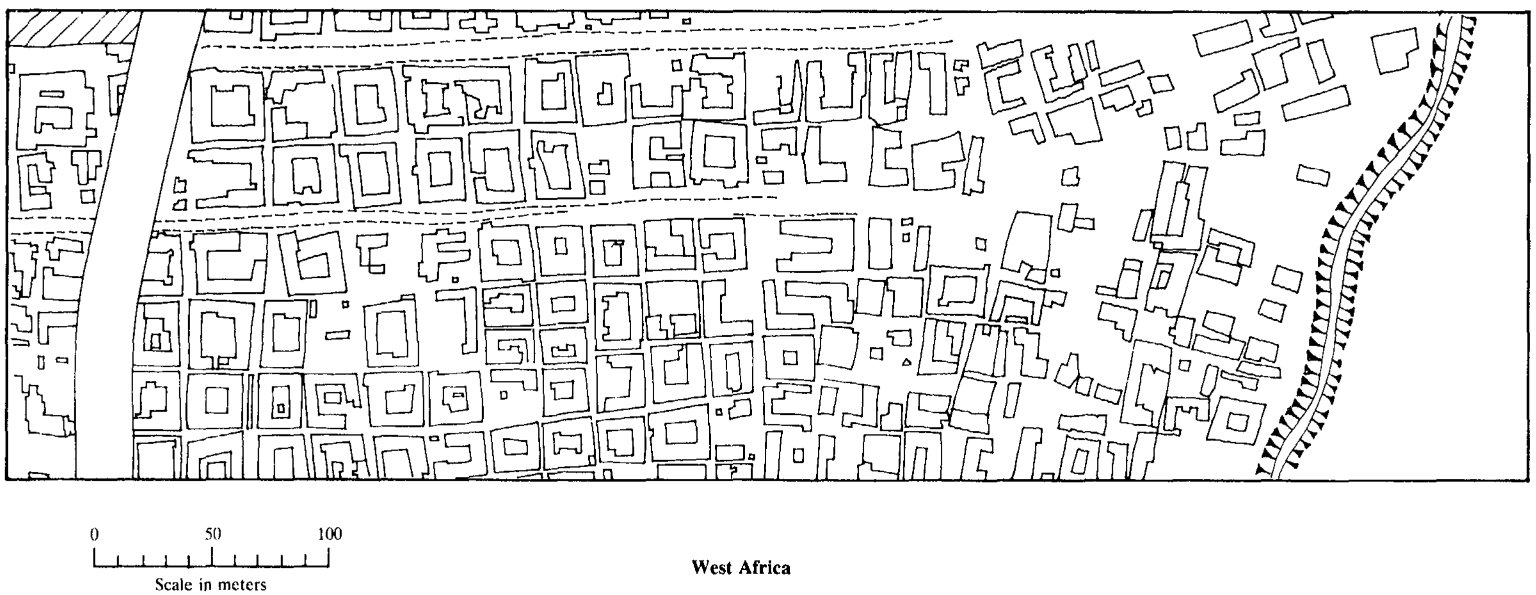
northern and southern limits of range; Bancroftian filariasis transmitted mainly by other mosquito species; Bancroftian filariasis transmitted mainly by *C. pipiens* complex; Residual Bancroftian filariasis transmission by *C. pipiens* complex.

Culex pipiens is a complex of mosquito species and subspecies. The main tropical species, and the vector of Bancroftian filariasis in those tropical areas where the infection is transmitted by Culex, is *Culex quinquefasciatus* (previously also known as *Culex pipiens fatigans*, *C. p. quinquefasciatus*, or *C. fatigans*). Other important species are *C. p. pipiens*, *C. p. molestus* (the probable vector of Bancroftian filariasis in Egypt), and *C. p. pallens*.

Source: Same as for map 12.

Figure 2-2. *Special Plan of Two Low-income Urban Residential Neighborhoods*





Source: The World Bank.

limiting factor, especially in urban areas. The crowding in single-story residential areas of two cities, East Asian and West African, where average population densities of 1,000 to 1,500 persons per hectare (100,000 to 150,000 per square kilometer) are found, is shown in figure 2-2. Space is valuable and most of it is occupied by houses. When streets and highways are brought in, buildings suffer by being moved or truncated. The addition of rental rooms to what was previously relatively spacious housing is shown in figure 2-3. The smaller of the two houses is occupied by 61 people, each of whom has an average of about 5 square meters of living space (from figure 2-3) and no more than 9 square meters of total space (equivalent to about 1,100 persons per hectare). Even under these conditions, there is room for extended household latrines using buckets or vaults. By way of comparison, sewered communal latrines would occupy up to 3 percent of total land area where population densities are about 1,000 persons per hectare and up to 10 percent if shower and laundry facilities are provided (not including space for clotheslines).

Levels of water supply service

Hand-carried supplies from a public water hydrant restrict feasible technologies to those not requiring water, such as VIP latrines, ROECs, and DVC toilets. PF toilets may be feasible in a sociocultural environment where anal cleansing practices already require the carrying of water to the toilet. Even then, however, a sufficient amount of water may not be available for flushing. A system that requires water to transport excreta is clearly not feasible. The facilities mentioned above can be converted to water-seal units, if desired, when the water supply service is improved by a yard or house connection.

Yard connections permit PF and vault toilets, but not cistern-flush toilets. If sullage generation exceeds 50 liters per capita daily, sewered PF toilets also become technically feasible. The choice among these additional possibilities and VIP latrines, ROECs, and DVC toilets, which are also still technically feasible, depends on other factors such as soil conditions, housing density, and consumer preferences.

Household connections make cistern-flush toilets with conventional sewerage or septic tanks and soakaways technically feasible. Sewered PF toilets are also possible; but they have high capital costs, and alternative improvements in sullage disposal may be economically more attractive. Sanitation technologies are very sensitive to water use. Figure 2-4 illustrates schematically how various levels of water use lead to different sanitation options.

Housing density

In densely populated urban areas, VIP latrines, ROECs, PF toilets, and septic tanks with soakaways may be infeasible. Conventional sewerage is feasible if gradients are steep enough to provide self-cleansing velocities. Sewered PF systems are also feasible and can be used for flatter gradients. Vacuum-truck cartage from vaults is a third possibility in dense areas. The choice among these possibilities is made essentially on economic grounds, although sullage disposal facilities and access for service vehicles are important for vault toilets.

It is not easy to define at which population density on-site systems (such as VIP latrines, ROECs, PF, and DVC toilets) become infeasible. The figure is probably most commonly around 250–300 persons per hectare for single-story homes and up to double that for two-story houses. Pit latrines, however, have been found to provide satisfactory service at much higher population densities. The essential point is to determine, in any given situation, whether or not there is space on the plot to provide two alternating pit sites that have a minimum lifetime of two years, or whether the pit could be easily emptied if space for alternating pit sites is not available. For off-site systems (such as vaults and cartage), the limiting factor is normally the accessibility of the vault, not population density—so that, in very crowded and irregularly laid-out areas, bucket latrines and communal facilities may be the only options.

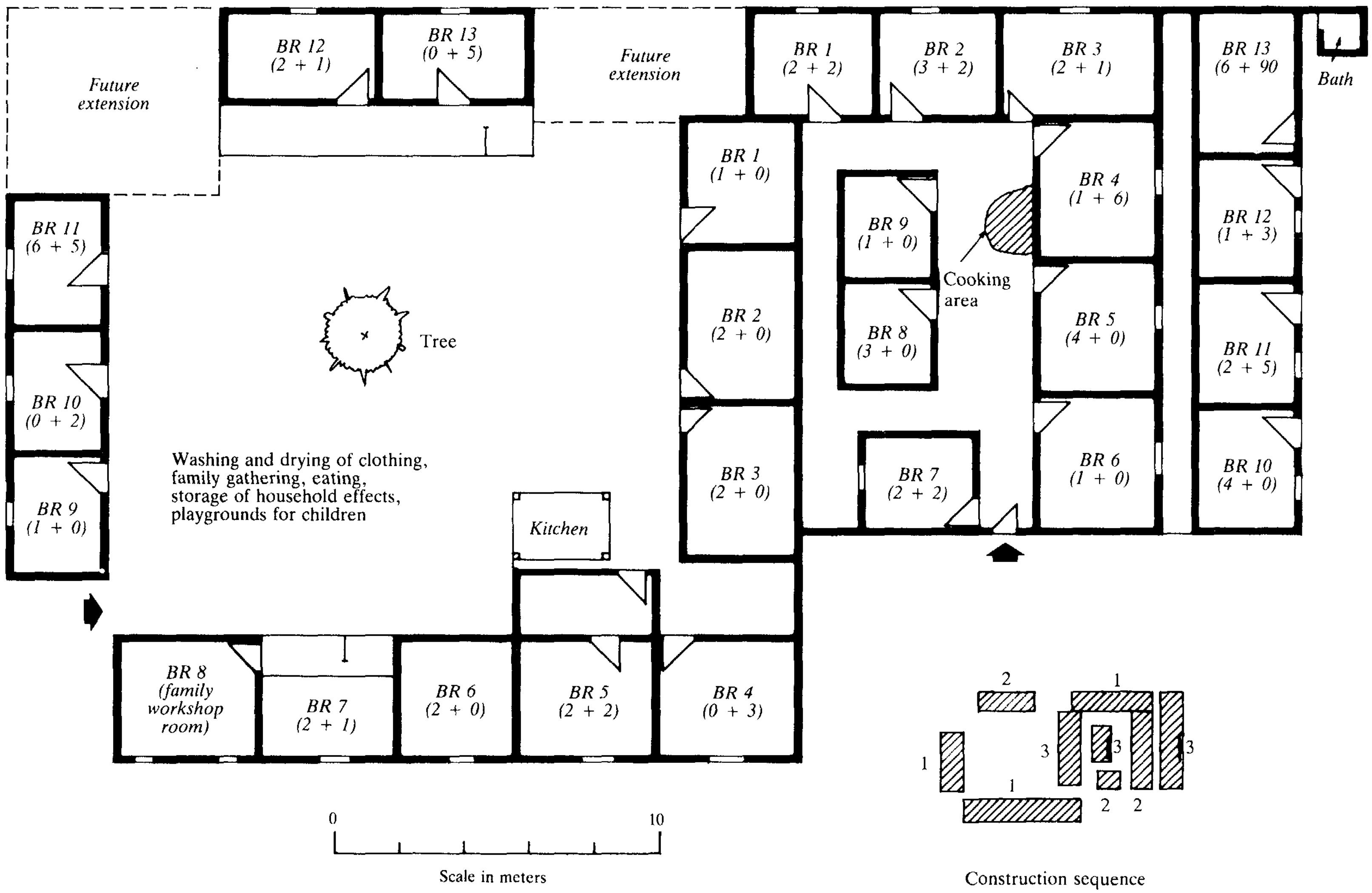
Complementary investments

Off-site night-soil or sewage treatment works are required for vault toilets, sewered PF toilets, and conventional sewerage systems. Sullage disposal facilities must be considered for all household systems and vault, bucket, and community facilities. For those systems, achieving disposal through reclamation (the reuse potential) must be thoroughly and realistically examined, especially in areas where excreta reuse is not a traditional practice. For example, DVC latrines may be provided where there is a demand for reuse. Other technologies that require off-site treatment facilities have high potential for sludge or night-soil reuse.

Potential for construction by homeowners

Where financial constraints are severe, the potential for "self-help" construction of the various technologies should be considered. Self-help can provide the unskilled labor and some (but not all) of the skilled labor required for the installation of VIP latrines, ROECs, and DVC and PF toilets. It requires organization and super-

Figure 2-3. *Typical Floor Plan of Low-income Rental Units*

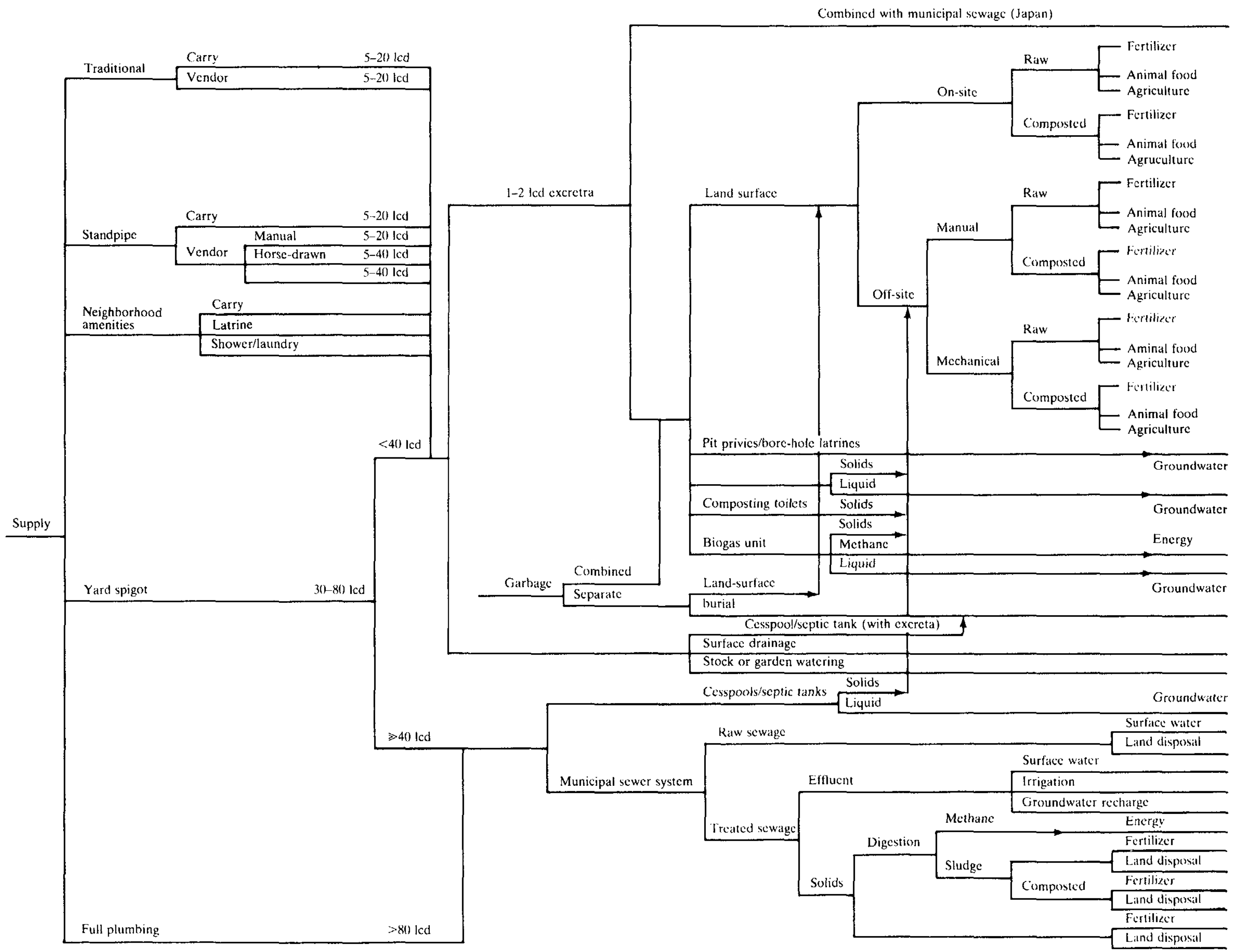


□ Served by standpipe; *BR* bedroom.

Note: Numbers in parentheses indicate numbers of adults and children in each bedroom.

Source: The World Bank.

Figure 2-4. *Schematic of Relations between Levels of Water Service and Options for Sanitation*



lcd Liters per capita daily.

vision by the local authority, especially in urban areas. The other technologies have less potential for self-help labor and, indeed, require experienced engineers and skilled builders for their design and construction.

Hygienic habits of users

The choice of anal cleansing materials, in particular, can affect the choice of technology. PF and cistern-flush toilets cannot easily dispose of some anal cleansing materials (for example, mud balls, corncobs, stones, or cement-bag paper) where a traditional practice of disposing of such anal cleansing materials outside the toilet does not exist. The practice of using water for anal cleansing may present problems for pit latrines in soil with limited permeability or for DVC toilets, the contents of which may become too wet for efficient composting.

Institutional constraints

Institutional constraints often prevent the satisfactory operation of sanitation technologies even when the technologies are properly designed because adequate maintenance (at the user or municipal levels or both) often cannot be provided. Thus, educational programs for users and institutional development should generally form an integral part of program planning for sanitation. Changes, especially those in social attitudes, can be accomplished only slowly and may require a planned series of incremental improvements over time.

Comparison of Technology

From the foregoing discussion of the factors affecting the selection of technology, the technical suitability of various technologies for application in a specific community can be determined. As a first step, comparative criteria must be defined. One possibility is to compare the technologies in a matrix that displays performance according to the established criteria. Such a matrix, which can serve as a guide for nontechnical readers and a convenient summary for professionals, is given in table 2-3. Ranking technologies by means of subjective weighting produces a numerical comparison of spurious precision. 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 comparison by numerical matrix of all possible technologies. The most useful function of a matrix, therefore, is to exclude certain technologies in a given situation, rather than to select the best. The choice among the remaining technologies is often based principally on considerations of cost, user preferences, and reliability. Algorithms to aid in the choice of technology are described in chapter 9.

Treatment Alternatives

The objectives of night-soil or sewage treatment are to eliminate pathogens so that human health will be protected and to oxidize organic matter so that odors, nuisance, and environmental problems (such as algal blooms or fish kills) will be eliminated. The first objective may be achieved by the separation of feces from the community and the second by various combinations of separation, sedimentation, digestion, and oxidation.

Details of conventional sewage treatment processes—designed primarily to oxidize organic matter—are described in standard sanitary engineering texts.[7] A review here of the objectives and principles of the health aspects of sewage treatment as they apply to developing countries, together with some principles of design of selected technologies particularly suited to the treatment of night soil and sewage in developing countries, is appropriate.

Conventional treatment processes

The conventional treatment observed in developing countries during this research had the technical disadvantages of extremely poor pathogen removal and frequent operation and maintenance problems from shortages of properly skilled personnel and imported spare parts.

Effluent from a trickling filter plant with about five hours of retention will contain significant concentrations of viruses, bacteria, and protozoa and helminth ova and is thus unsuitable for unlimited reuse in agriculture. Activated sludge plant effluent with, say, twelve hours of retention, is better than that from trickling filters but will still be microbiologically contaminated.

Batch digestion of sludge for 13 days at 50°C in a heated digester will remove pathogens and reduce volatile solids by some 50 percent. Digestion at 30°C for 28 days will remove protozoa and most enteroviruses. Digestion for 120 days at ambient temperatures will remove all pathogens except helminths. Sludge drying for at least three months will be very effective against all pathogens except helminth ova (see chapter 4).

Other methods of sewage treatment that are used in industrial countries include oxidation ditches, aerated lagoons, sand filtration, chlorination, and land treatment; these are described in a number of standard works.[8]

Waste stabilization ponds

Waste stabilization ponds are large, shallow ponds in which organic wastes are decomposed by a combination of bacteria and algae. The waste fed into a stabilization pond system can be raw sewage, effluent from sewered PF toilets or aquaprivies, or diluted night soil.

Waste stabilization ponds are an economical method of sewage treatment wherever land is available. Their principal technical advantage in developing countries is that they remove excreted pathogens with much less required maintenance than any other form of treatment. A pond system can be designed to ensure, with a high degree of confidence, the elimination of all excreted pathogens. This is normally not done in practice because the additional benefits resulting from achieving zero survival, rather than very low survival, are less than the associated incremental costs. There are three types of ponds in common use:

- Anaerobic pretreatment ponds for BOD reduction, particularly for strong wastes—retention times are one to five days and depths are 2–4 meters.
- Facultative ponds, in which oxygen for further biooxidation of the organic material is supplied principally by photosynthetic algae—they have retention times of five to thirty days (sometimes more) and depths of 1–1.5 meters.
- Maturation ponds for final settling and pathogen removal that receive facultative pond effluent and are responsible for the quality of the final effluent—they have retention times of five to ten days and depths of 1–1.5 meters.

Minimum designs incorporate a facultative pond and two or more maturation ponds; for strong wastes (BOD_5—biochemical oxygen demand by the standard test—of >400 milligrams per liter), the use of anaerobic ponds as pretreatment units ahead of facultative ponds will minimize the land requirements of the pond system. Well-designed pond systems in warm climates—incorporating five ponds in series and having a minimum overall retention time of thirty days—produce an effluent that will be essentially pathogen free and suitable for unlimited irrigation reuse.

Snail and mosquito breeding in stabilization ponds will occur only if poor maintenance allows vegetation to emerge from the pond bottom or to grow down the embankment into the pond, since these conditions create shaded breeding sites. This can be prevented by providing pond depths of at least 1 meter and concrete slabs or stone riprap at the upper water level.

Aerobic composting

Rapid stabilization and pathogen destruction is ensured by aerobic composting, in which raw night soil or sludge is mixed with straw or some other organic matter or with previously composted night soil (or a combination of these) so as to provide a water content of 40–60 percent, a carbon to nitrogen ratio of 20–30:1, and bulk or workability of the mixture. This technology has been applied in the United States (notably, at the U.S. Department of Agriculture's Beltsville Agricultural Research Center [BARC], Beltsville, Maryland) to raw and digested sludge and to night soil. The least expensive scheme is to form windrows of the night-soil mixture over loops of perforated irrigation drainage pipe laid on the ground. Air is then drawn intermittently through the pile into the pipe by a ⅓-horsepower blower and expelled as exhaust through a small pile of finished compost to reduce odors. Equipment requirements are limited to front-end loaders and blowers; screens may be added if the bulking materials are to be separated and recycled. Temperatures in the pile are high enough (even in winter) for a sufficient time to ensure complete pathogen destruction. The operation is simple and reliable (figure 2-5).

Other schemes for sludge or night-soil treatment include incineration, wet oxidation, and pyrolysis; they are too expensive to be considered for general application in developing countries.

Sullage Disposal

The adoption of any of the sanitation technologies, with the exception of septic tanks and conventional sewerage, requires that separate facilities be considered for sullage disposal. Sullage is defined as all domestic wastewater other than toilet wastes; it includes laundry and kitchen wastes as well as bathwater. It contains some excreted pathogens but, of course, considerably fewer than toilet wastes. It also contains many organic compounds and approximately 40–60 percent of the total household production of waste organics—that is, some 20–30 grams of BOD_5 per capita daily. This figure, however, depends on water consumption. A family with abundant water for personal and clothes washing and many water-using appliances will generate more sullage BOD than one that uses only small quantities of water for drinking and cooking.

Table 2-3. *Descriptive Comparison of Sanitation Technologies*

Sanitation technology	*Rural application*	*Urban application*	*Construction cost*	*Operating cost*	*Ease of construction*	*Self-help potential*
VIPs and ROECs	Suitable	Suitable in L/M-density areas.	L	L	Very easy except in wet or rocky ground	H
PF toilets	Suitable	Suitable in L/M-density areas	L	L	Easy	H
DVC (double vault composting) toilets	Suitable	Suitable in L/M-density areas	M	L	Very easy except in wet or rocky ground	H
Self-topping aquaprivy	Suitable	Suitable in L/M-density areas	M	L	Requires some skilled labor	H
Septic tank	Suitable for rural institutions	Suitable in L/M-density areas	H	H	Requires some skilled labor	L
Three-stage septic tanks	Suitable	Suitable in L/M-density areas	M	L	Requires some skilled labor	H
Vault toilets and cartage	Not suitable	Suitable	M	H	Requires some skilled labor	H (for vault construction)
Sewered PF toilets, septic tanks, aquaprivies	Not suitable	Suitable	H	M	Requires skilled engineer/builder	L
Sewerage	Not suitable	Suitable	H	H	Requires skilled engineer/builder	L

Note: L, low; M, medium; H, high; VH, very high.
a. On- or off-site sullage disposal facilities are required for nonsewered technologies with water service levels in excess of 50 to 100 lcd, depending on population density.
b. If groundwater is less than 1 meter below the surface, a plinth can be built.

In developing countries sullage is a wastewater with approximately the same organic pollution potential as raw sewage in North America. Although its environmental impact may be moderate (see the Kyoto case study, below), its health hazard will be many orders of magnitude less than that of sewage (see chapter 4). Thus, an important factor to consider when choosing sullage disposal facilities is how much the community is willing to spend on environmental protection.

There are basically four kinds of sullage disposal systems: casual tipping in the yard or garden, on-site disposal in seepage pits, disposal in open drains (usually stormwater drains), and disposal in covered drains or sewers. The first will be adequate where water use is low and the soil and climatic conditions are such that the yard remains dry and puddles of water do not form. Seepage pits can handle more water but also require appropriate soil conditions. If stormwater drains are used for sullage disposal, they should be designed with a deep (rather than flat) center section so that the small volumes of dry weather flow and sullage will not pond. In addition, drains must be carefully maintained to be free of debris that could block the flow and thereby provide attractive sites for mosquito breeding. Disposal in covered drains or sewers is subject to the same excavation and environmental problems as conventional sewerage.

Resource Recovery

Technologies for resource recovery in areas included within the present research provide for irrigation with treatment plant effluent; garden watering with sullage; crop fertilization by raw, digested, or anaerobically composted night soil or sludge; fish culture with raw night soil; and methane production from municipal sludge or night-soil digesters and from household biogas units.

Readily available data on health aspects were collected, but were not sufficiently detailed to show either presence or absence of detrimental effects from the various resource-recovery practices. Technologies characteristic of these and similar practices are presented in ***Appropriate Sanitation Alternatives: A Planning and Design Manual***; their general features are summarized below.

Water requirement	*Required soil conditions*	*Complementary off-site investment*[a]	*Reuse potential*	*Health benefits*	*Institutional requirements*
None	Stable permeable soil; groundwater at least 1 meter below surface[b]	None	L	Good	L
Water near toilet	Stable permeable soil; groundwater at least 1 meter below surface[b]	None	L	Very good	L
None	None (can be built above ground)	None	H	Good	L
Water near toilet	Permeable soil; groundwater at least 1 meter below surfacc[b]	Treatment facilities for sludge	M	Very good	L
Water piped to house and toilet	Permeable soil; groundwater at least 1 meter below surface[b]	Off-site treatment facilities for sludge	M	Very good	L
Water near toilet	Permeable soil; groundwater at least 1 meter below surface[b]	Treatment facilities for sludge	M	Very good	L
Water near toilet	None (can be built above ground)	Treatment facilities for night soil	H	Very good	VH
Water piped to house and toilet	None	Sewers and treatment facilities	H	Very good	H
Water piped to house and toilet	None	Sewers and treatment facilities	H	Very good	H

Agricultural reuse

Agricultural reuse is the most common form of excreta reuse. There are, however, health risks to people and animals working in the fields where excreta are reused and to those who consume the crops raised in excreta-enriched soil. There are also problems associated with the chemical quality of the compost, sludge, or sewage effluent—including concentration in crops of heavy metals and potential damage to the soil structure from high sodium concentrations.

Pigs are fed raw excreta in a number of South and Southeast Asian, Central American, and West African locations. They provide direct and efficient conversion of wastes to protein, but the health risks are obvious, and reliable epidemiological data are lacking. Thorough cooking of pork from excreta-fed swine is an essential measure of effective pathogen control.

Aquacultural reuse

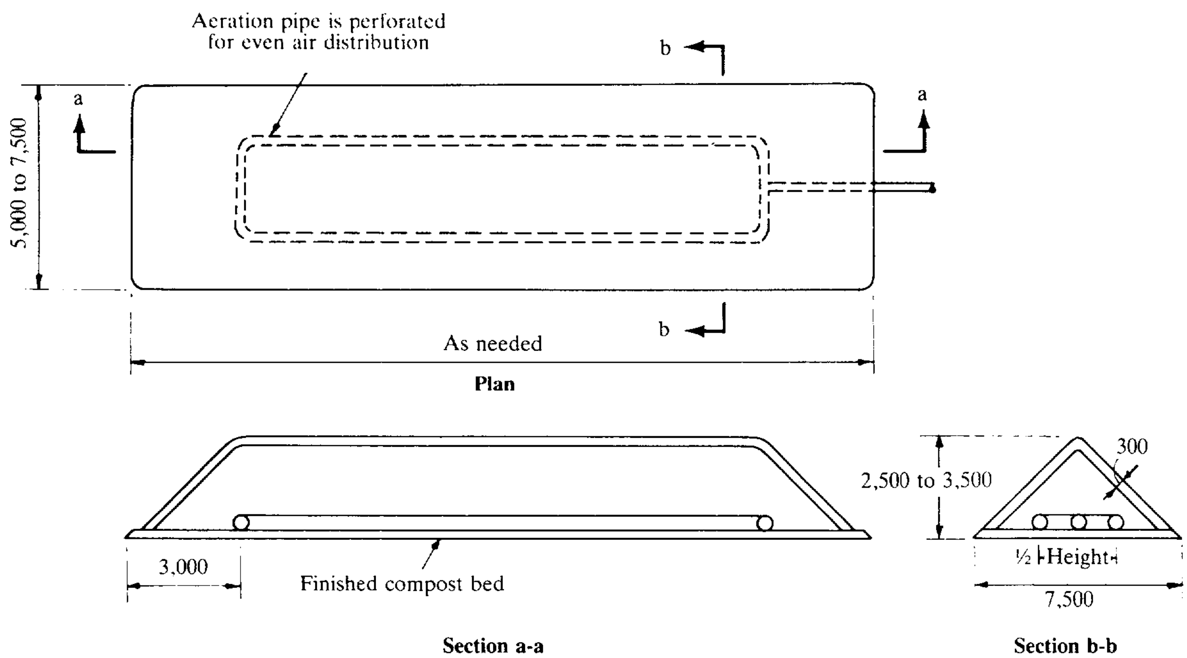
Human excreta can be used for raising aquatic plants and animals. The four main kinds of aquaculture are freshwater fish farming; marine culture of fish, shellfish or shrimp; production of algae; and the emergent production of aquatic plants.

Reliable data on freshwater fish farming are available from South and Southeast Asia. In this practice there are hazards of passive carriage of a range of pathogens and, in some parts of the world, of *Clonorchis sinensis* (Chinese liver fluke) transmission as well. Control measures include enriching ponds only with settled sewage or stored night soil or sludge; placing the fish in clean water for several weeks prior to harvesting; clearing vegetation from pond banks to discourage the snail host of *Clonorchis*; promoting food hygiene in the handling and processing of fish; and discouraging the consumption of raw or undercooked fish.

Yields of carp in fertilized ponds vary from 200 kilograms per hectare yearly in rural, subsistence ponds to 1,000 kilograms per hectare or more yearly in commercial ponds; yields of tilapia are 2,000–3,000 kilograms per hectare yearly in well-maintained ponds. Fish yields can be doubled by raising ducks, whose feces provide additional nutrients, on the ponds. 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. Up to 7,000 kilograms per hectare yearly can be achieved if supplemental feeding with grass, other vegetation, rice bran, groundnut cake, or the like is provided and bottom-feeding fish are added to the pond.

The design of fishponds is essentially the same as that of waste stabilization ponds. Depths are usually >1

Figure 2-5. *Schematic of Beltsville Agricultural Research Center (BARC) System for High-rate Thermophilic Composting*
(meters)



Note: BARC (Beltsville, Maryland) is a facility of the U. S. Department of Agriculture.

meter to prevent vegetation from emerging from the pond bottom; deep ponds (>2 meters) are disadvantageous because there is little oxygen, and hence few fish, in the lower layers. What matters is the correct rate of supply of nutrients; regular batch feeding on an empirically determined basis is recommended.

Biogas production

Institutional and household biogas plants are operative in China, India, Korea, the island of Taiwan, and elsewhere and use diluted animal feces with or without human excreta and with or without vegetable refuse. The effluent slurry from these plants can be used in agriculture and fishponds. The dung from one cow or similar animal can produce around 500 liters of gas per day; it contains 50–70 percent methane and its calorific value is around 4–5 kilocalories per liter. In contrast, human excreta yields only 30 liters of gas per person daily. The process is very sensitive to temperature, and gas production is negligible below 15°C.

One family in Korea reported sufficient gas production for cooking purposes for nine months of the year from human and household wastes. Another, on the island of Taiwan, was completely self-sufficient in cooking fuel with the added wastes from two pigs. Biogas may also be used for lighting, and large farms and institutions are also suitable sites for biogas units.

Example of Management Schemes for Sewage and Night Soil

An excellent comparison of well-designed, well-managed systems for excreta and sullage disposal can be found in Kyoto, Japan, a city of 1.4 million. Here, public health and aesthetic requirements are met by conventional sewerage for about 40 percent of the population and by a vault and vacuum-truck system for another 40 percent. Sullage from the latter is discharged to surface drainage facilities. After collection, the 1.2 liters per capita daily of night soil undergo grit removal, comminution, screening, and storage and are released into sewers at off-peak hours for subsequent activated sludge treatment and incineration. Trucks are thoroughly cleaned at the night-soil transfer station after each trip.

The areas and water quality of streams in portions of the city served by the two systems are shown in map 20. Diffused discharges of sullage from unsewered areas do not affect concentrations of BOD and suspended solids in the streams; increases in these constituents cannot be distinguished from those due to urban runoff in sewered areas. Moderate increases in stream BOD and solids downstream from the sewage treatment plants reflect both the excellent removals obtained by treatment and the impact of point discharges to the streams. Health data from the two areas reveal no differences. Costs of the two systems are presented in the following chapter.

The most significant findings from this case study are that the less expensive vault and vacuum-truck system can provide health protection equal to, and protection of water quality in streams better than, that of conventional sewerage. Both systems are providing reliable service to areas of an historic, beautiful, and modern city.

Future Research Needs

Most of the technologies discussed in this chapter have been applied successfully at specific sites and, in the case of on-site systems, on an individual basis. It is therefore necessary to design, implement, and monitor pilot projects on a community scale to:

- Confirm the replicability of technologies
- Test the transfer and adaptation of technologies for different sociocultural environments
- Evaluate the ability of communities to organize and operate communal systems such as the emptying of vaults and septic tanks
- Determine effects of sullage disposal and develop methods of sullage disposal for various population densities
- Test the large-scale application of appliances with low water use (for example, aerated spigots and shower heads, overhead low-volume flush tanks) and their effects on sanitation.

Research is also needed in various areas to develop technologies further, to measure their effects, or to find new, more efficient techniques. Among these areas for further research are:

- On- and off-site sullage treatment and disposal methods (infiltration, evaporation, anaerobic filtration, oxidation ponds)
- Testing and monitoring of the performance of handpumps for water supply in rural areas and development of a methodology for selection (similar to that of the algorithms for sanitation) that would reduce present high failure rates of handpumps
- Development of training materials, workshops, and seminars for disseminating information on low-cost water supply and sanitation systems and for training professionals and technicians in implementation
- Development of a methodology to determine the most cost-effective mix of sewerage and low-cost sanitation in urban areas
- Multidisciplinary evalution and pilot testing of methods to convert waste materials into usable products.

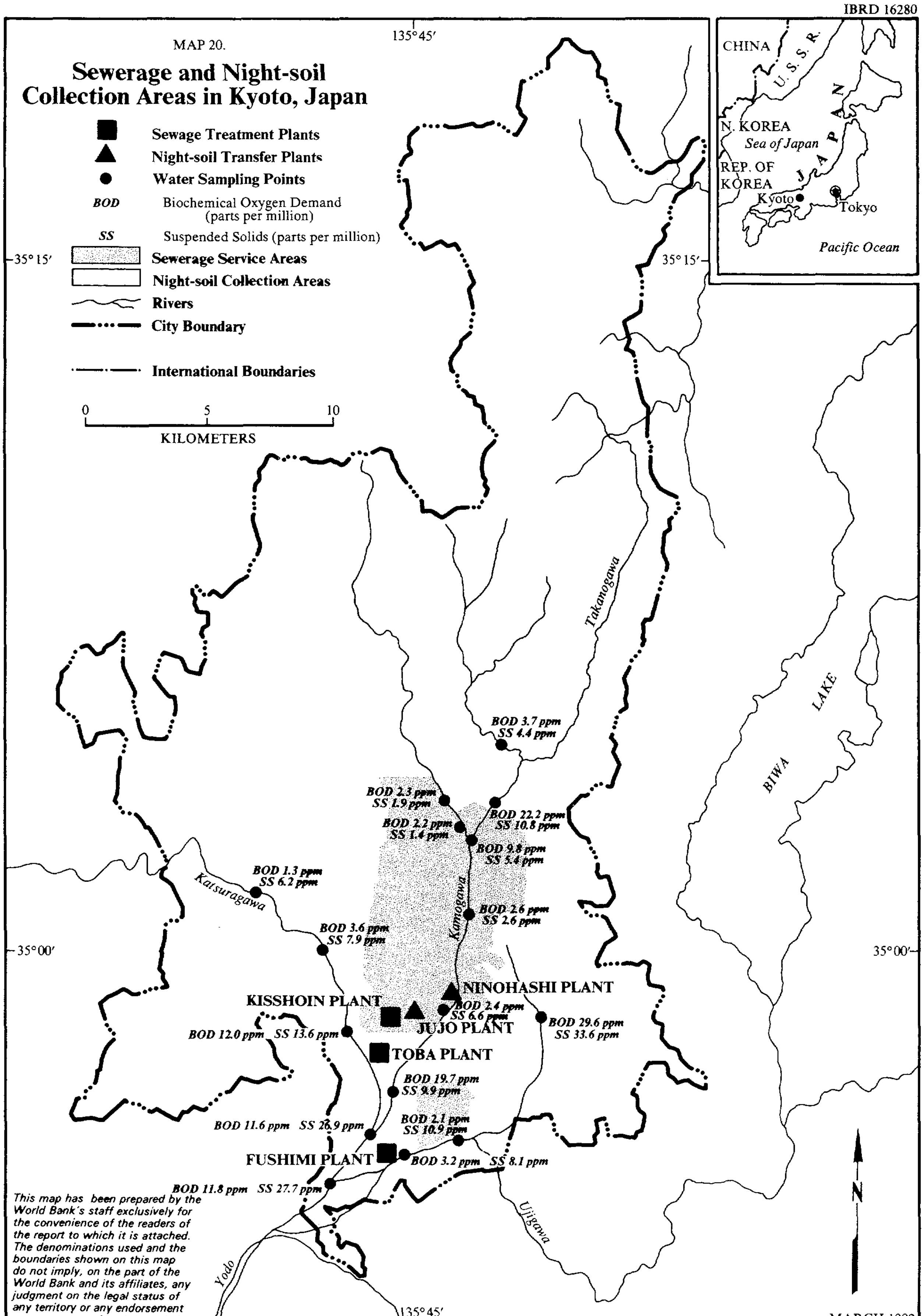
Much work has been done in this last area, but usually only with a narrow (single-purpose) orientation. A multidisciplinary approach—studying many disposal and reuse possibilities and optimizing various simultaneous outputs—will result in more efficient and cost-effective solutions.

Conclusion

The review of existing technologies shows clearly that low-cost sanitation methods exist that are either acceptable as now used (for example, PF and vault latrines) or capable of easy improvement (VIP latrines). Selection of the technique to be used depends on local conditions such as climate, soil permeability, social customs, and the like. All technologies identified provide the health benefits commonly associated with waterborne sewerage, albeit at different standards of convenience. In short, the choice is not between different levels of health and sanitary conditions but between service levels and affordability. Fortunately, this choice is made even easier by the fact that technologies can be upgraded over time to achieve higher standards of service that keep pace with the users' ability to pay for them (see chapter 9).

The most important consideration for the selection of sanitation technology is existing and anticipated water consumption of the area studied. At low water use (say, less than 50 liters per capita daily), sullage can usually be disposed of on site without major problems. Above this level, on-site disposal becomes more difficult, and, at levels above 100 liters per capita daily, some sort of drainage is probably required. Again, local conditions such as population density and soil permeability will also be determining factors. It is clear, however, that the lower the water consumption, the greater are the options for on-site disposal methods. For the same reason (maximum number of options), sullage and excreta should be disposed of separately.

Selection of the technology suitable in any given case


IBRD 16280
MAP 20.
Sewerage and Night-soil Collection Areas in Kyoto, Japan
Sewage Treatment Plants
Night-soil Transfer Plants
Water Sampling Points
BOD Biochemical Oxygen Demand (parts per million)
SS Suspended Solids (parts per million)
Sewerage Service Areas
Night-soil Collection Areas
Rivers
City Boundary
International Boundaries
0 5 10
KILOMETERS
135°45′
35°15′
35°00′
CHINA
U.S.S.R.
N. KOREA
Sea of Japan
REP. OF KOREA
JAPAN
Kyoto
Tokyo
Pacific Ocean
Takanogawa
BIWA LAKE
Katsuragawa
Kamogawa
Ujigawa
Yodo
BOD 3.7 ppm SS 4.4 ppm
BOD 2.3 ppm SS 1.9 ppm
BOD 2.2 ppm SS 1.4 ppm
BOD 22.2 ppm SS 10.8 ppm
BOD 9.8 ppm SS 5.4 ppm
BOD 1.3 ppm SS 6.2 ppm
BOD 2.6 ppm SS 2.6 ppm
BOD 3.6 ppm SS 7.9 ppm
NINOHASHI PLANT
KISSHOIN PLANT
BOD 2.4 ppm SS 6.6 ppm
JUJO PLANT
BOD 29.6 ppm SS 33.6 ppm
BOD 12.0 ppm SS 13.6 ppm
TOBA PLANT
BOD 19.7 ppm SS 9.9 ppm
BOD 11.6 ppm SS 26.9 ppm
BOD 2.1 ppm SS 10.9 ppm
FUSHIMI PLANT
BOD 3.2 ppm SS 8.1 ppm
BOD 11.8 ppm SS 27.7 ppm
This map has been prepared by the World Bank's staff exclusively for the convenience of the readers of the report to which it is attached. The denominations used and the boundaries shown on this map do not imply, on the part of the World Bank and its affiliates, any judgment on the legal status of any territory or any endorsement or acceptance of such boundaries.
MARCH 1982

requires a consideration of various factors in addition to purely technical ones. For an initial evaluation, a matrix comprising the various characteristics of available technologies is sometimes helpful. For final selection, however, the algorithms described in chapter 9 should be used. Both the matrix and algorithms emphasize the need to take a comprehensive look at the proposed solution—that is, the sociocultural aspects as well as the technical, financial, and economic considerations—to avoid the installation of a system that will not be used or will be quickly abandoned by the community.

Notes to Chapter 2

1. For engineering designs and detailed technical information on each technology, see also John M. Kalbermatten and others, *Appropriate Sanitation Alternatives: A Planning and Design Manual*, World Bank Studies in Water Supply and Sanitation, no. 2 (Baltimore: Johns Hopkins University Press, forthcoming). Much of the technical description presented in this chapter is taken from this companion work.

2. As is discussed in chapter 4, a well-designed and -maintained pit latrine can provide the same level of health benefits in low-density areas as a properly maintained sewerage system can in the inner city.

3. Latrines have been used satisfactorily at twice this suggested density in areas where soil conditions or climatic factors are especially favorable.

4. Sullage is wastewater that does not contain excreta—for example, laundry water and bathwater.

5. Japanese experience has been that there is a lag time of five to ten years between commissioning of a sewerage system and voluntary connection to it by a significant number of households.

6. For further detail, see chapter 4 and Richard G. Feachem and others, *Sanitation and Disease: Health Aspects of Excreta and Wastewater Management*, World Bank Studies in Water Supply and Sanitation, no. 3 (Baltimore: Johns Hopkins University Press, forthcoming), a companion to this study.

7. For example, Gordon M. Fair, John C. Geyer, and Daniel A. Okun, *Water Purification and Wastewater Treatment and Disposal* (New York: John Wiley and Sons, 1968).

8. Ibid. See also D. Duncan Mara, *Sewage Treatment in Hot Climates* (New York: John Wiley and Sons, 1976).

3
The Economic Comparison

COMPARATIVE COSTING lies at the heart of the analysis of alternative sanitation technologies. The definition of technological "appropriateness" developed in chapter 1 is based partly upon a systematic ranking of feasible alternatives according to their economic costs. Implicit in this definition is the search for a common denominator for the objective comparison of diverse systems. That common denominator should reflect both the positive and negative consequences of a given technology and also indicate its overall "score"—either on an objective scale or relative to other alternatives.

One scoring measurement commonly used in project evaluation is the benefit-cost ratio.[1] It has the advantage of providing a single, summary figure representing the net economic effect of a given project, which can then be readily compared with that of alternative projects. The disadvantages of benefit-cost calculations are that they do not easily accommodate noneconomic benefits and costs (particularly if these are unquantifiable); they may give misleading results when applied to mutually exclusive projects; and they may not reflect macroeconomic goals such as the creation of employment or the generation of savings and investment. Fortunately, the last two problems can be remedied by variations of the basic calculations.[2] The difficulties of measuring benefits for sanitation projects, however, cannot be readily overcome. Indeed, in the case of water supply projects it has been concluded that the theoretical and empirical problems involved in quantifying incremental health benefits are so great as to make serious attempts at the measurement of benefits inappropriate as part of project appraisals.[3]

There are also unquantifiable costs associated with alternative sanitation technologies. Although it is generally possible to assess qualitatively the environmental consequences of installing a particular system, it is very difficult to quantify them since no "market" for such public goods exists. It is even more difficult to compare consequences of installation with the environmental situation that would develop without the project's implementation, thus to determine net benefit or net cost figures.

A scoring device that has been used on occasion for ranking alternatives with unquantifiable benefits is a matrix that lists both cost and benefit components and assigns values (or relative ranks) to each alternative based on an arbitrary scale (or the total number of alternatives). Varying degrees of complexity can be built into matrix ranking by weighting the criteria or by using complex, summary variables of the values. Regardless of the variations, however, the lack of objectivity in the procedure remains a major disadvantage. It is unlikely that two equally competent analysts would arrive at the same value for various alternatives or even the same ranking across alternatives. There is no objective basis for selecting one summary measure over another or any one set of weights for the cost and benefit categories. Such a nonreplicable method is not only unscientific but can be misleading to the nontechnical reader, who may mistake its statistical complexities for objectivity.

In general, there is no completely satisfactory scoring system for comparing alternatives with unquantifiable benefits. Only in the case of mutually exclusive alternatives with identical benefits can a cost-minimization rule be applied. In such cases the alternative with the lowest present value of cost, when discounted at the appropriate rate of interest, should be selected. For given levels and qualities of service, the least-cost alternative should be preferred. But, where there are differences in the output or service, the least-cost project often will not be the economically optimal one.

Alternative sanitation systems provide a wide range of benefit levels. Although most properly selected systems can be designed to provide the potential for full health benefits (that is, to ensure pathogen destruction), the convenience to users offered by an indoor toilet with sewer connection is hard to match with a pit privy. Many benefits exist in the mind of the user, and varying qualities of service result in varying benefit levels. For this reason, a least-cost comparison will not provide sufficient information to select among sanitation alternatives. Nonetheless, if properly applied, it will provide an objective, common denominator that reflects tradeoffs in cost corresponding to different service standards. Once comparable cost data have been developed, the consumers or their community representatives can make their own determination of how much they are willing to pay to obtain various standards of service.

Thus, the economic evaluation of alternative sanitation technologies comprises three components: comparable economic costing, the maximizing of health benefits from each alternative through proper design, and the involvement of users in making the final cost-benefit determination. This chapter deals with the first of these. Chapter 4 discusses the public health aspects of sanitation alternatives, and chapter 5 develops methods of promoting the involvement of users in choosing technology.

Economic Costing in Theory

The primary intent of economic costing is to develop a price tag for a good or service that represents the opportunity cost to the national economy of producing that good or service. Translated into practice, this intent can be summarized in three principles to be followed in preparing cost estimates.

The first principle is that all costs to the economy, regardless of who incurs them, should be included. In comparing costs of public goods such as water or sanitation, too often only costs that the public utility pays are considered in a cost comparison. The costs borne by the household are often ignored. In analyzing the financial implications of alternative technologies, such a comparison would be appropriate. For an economic comparison (that is, for the determination of the least-cost solution), however, it is necessary to include all costs attributable to a given alternative—whether borne by the household, the utility, the national government, or other entities.

The determination of which costs to include should rest on a comparison of the situation over time, with and without the project. This is not the same as a "before and after" comparison. Rather than using the status quo for the "without" scenario, the analyst must estimate how the current situation would improve or deteriorate over the project period were the project not to be undertaken. In the case of sanitation systems for urban fringe areas, for example, the costs of groundwater pollution and the difficulty in siting new latrines are likely to increase over time as population pressure mounts. There is likely to be an optimal time to undertake a sanitation project. By acting too soon the community may incur costs that could have been postponed. By waiting too long, the community might face a rise in the per capita cost of the project (in real terms) because of increases in population density, for example, which could aggravate construction difficulties for some technologies.

Once the relevant costs to be included have been identified, the second costing principle concerns the prices that should be used to value those costs. Since the objective of economic costing is to develop figures reflecting the cost to a particular country of producing a good or service, the economist is concerned that unit prices represent the actual resource endowment of that country. Thus, a country with abundant labor will have relatively inexpensive labor costs because labor's alternative production possibilities are limited. Similarly, a country with scarce water resources will have expensive water costs, in the economic sense, regardless of the regulated price charged to the consumer. Only by using prices that reflect actual resource scarcities can the economist ensure that the least-cost solution will make the best use of a country's resources.

Because governments often have diverse 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 often necessary to "shadow price" observed, or market, prices to arrive at meaningful costs for components of a sanitation technology. Calculating these shadow rates, or conversion factors, is a difficult task and requires intimate knowledge of an economy's workings.[4] The shadow rates used in this report were obtained from World Bank economists specializing in the countries concerned.

One of the most important shadow values is the opportunity cost of capital. This is defined as the marginal productivity of additional investment in the best alternative use. It can also be thought of as the price (or yield) of capital. In countries where capital is abundant, such as the industrialized countries of Europe, one expects the yield on capital to be relatively low. This is because capital has already been employed in its most productive uses and is now being substituted for labor or other inputs in less and less profitable areas. In many developing countries, however, capital is a scarce commodity and therefore has a relatively high opportunity cost and should be used in those areas where it produces a very high return. Therefore, a least-cost comparison of alternatives that differ in their capital intensity should reflect the real cost of capital to the economy rather than use capital's market price.[5]

The third principle of economic costing is that incremental rather than average historical costs should be used. This principle rests upon the idea that sunk costs (those already incurred) should be disregarded in making decisions about future investments. Analysis of the real resource cost of a given technology must value the components of that technology at their actual replacement cost rather than at their historical price. In the case of sanitation systems, this is particularly important in the evaluation of water costs. 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. If the analyst used the average cost of producing today's water, the evaluation would seriously underestimate the cost of obtaining water in the future. The decision to install a water-carried sewerage system will increase the newly served population's water consumption by around 50 to 70 percent.[6] Thus, in calculating the costs of such an alternative, it is extremely important to value properly the cost of the additional water required.

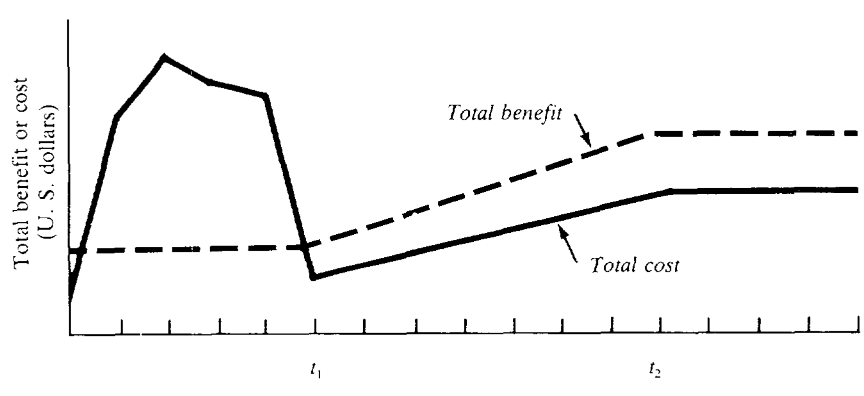
Special Problems of Sanitation Projects

The application of these costing principles to sanitation projects is difficult for several reasons. The chief difficulty is the problem of finding a scaling variable that allows comparison among diverse technologies that are designed to serve different numbers of people. On-site systems, such as pit latrines, are generally designed for a single family or household. The latrine's overall lifetime will depend on how many people use it. The life of some components (such as a vent pipe), however, may be independent of usage, so that the annuitized per capita construction cost of a latrine used by six people will probably not be the same as that of one used by ten people. For this reason, all costs presented in this chapter are given in household as well as per capita units.

A further difficulty is that the per capita construction cost of a sewerage system will vary considerably as the design population varies. In addition, it would be misleading to use the design population in deriving per capita sewerage costs to compare with those of a pit latrine. In the case of sewerage, the benefits only reach a portion of the users during the early years. The latrine's "design population," in contrast, is served immediately upon completion of the facility. Any technology that exhibits economies of scale will result in a diversion of the cost and benefit streams. With such a facility, the investment costs are incurred at the beginning of its lifetime and the benefits (services) are realized gradually over time. A schematic representation of this diversion between cost and benefit streams is provided in figure 3-1. The construction period lasts until T_1, when the new facility is commissioned and begins to produce benefits. As demand grows over time, more and more of the plant's capacity is utilized until, at T_2, the facility is fully used and provides full benefits (that is, serves its design population).

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 case of the derivation of per capita costs, this means that serving a person five 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 understate its real per capita cost when compared with that of a system that is fully utilized upon completion.

Figure 3-1. *Benefit-Cost Divergence over Time*



t_1 Time of sanitation facility's commissioning; t_2 time of full use of facility's capacity.

A good method that has been used to overcome the problem of rates of capacity utilization differing across systems is the average incremental cost (AIC) approach.[7] The per capita AIC of a system is calculated by dividing the sum of the present value of construction (C) and incremental operating and maintenance (O) costs by the sum of the present value of incremental persons served (N):

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

where r is the opportunity cost of capital and T is the life of the facility. All costs are in constant (noninflated) prices and have been appropriately shadow priced. For a system that is fully utilized immediately, this calculation reduces to the familiar calculation of annuitized capital and incremental operating and maintenance costs divided by the design population.

In practice it is often easier to calculate the AIC on the basis of a volume measure (for example, cubic meters) rather than by person served. For the sewerage costs in this study from the cities of Gaborone, Khartoum, Malacca, Managua, and Ndola, the AIC per cubic meter was calculated first because year-by-year projections of treated wastewater were available. These volumetric costs were then transformed into per capita and per household costs using per capita demand figures.

The AIC method is useful in deriving per capita costs that can be meaningfully compared with those of systems with different rates of use. This is especially important in evaluating sanitation systems because of the large variation in economies of scale (for example, sewerage versus on-site systems or cartage). Whereas economies of scale are often the engineer's best friend (in the sense that he can overdesign "to be on the safe side" without incurring unduly large increases in cost), they cause institutional and financial headaches when demand assumptions turn out to be optimistic or the city grows in a different direction from the one expected. Because of the inflexibility of large-scale sanitation systems once they are built, their financial feasibility, and even technical success, is extremely sensitive to the assumptions used in the design analysis. In communities where there is no demand history on which to base forecasts, it is extremely risky to recommend a system with large economies of scale and with a correspondingly long design period.[8]

An additional problem in deriving comparable costs for sanitation systems is the differing treatment of sullage wastes. In sewerage, most septic tanks, and some aquaprivy systems, sullage is disposed of along with excreta. In most of the on-site technologies, sullage disposal must be accomplished separately, through stormwater drains or ground seepage. If stormwater drains are present (or would be constructed anyway), then the incremental cost of disposing of sullage is very small because storm drains are usually designed to handle flood peaks.[9] If sullage is left to soak into the ground, nuisance and possible health risks may be created (depending on climate, soil conditions, and groundwater tables).[10] Alternatively, separate disposal of sullage may be considered a positive benefit in areas where the population recycles kitchen and bathwater to irrigate gardens or dampen dust. In such cases, the removal of sullage through the introduction of a sewerage system would produce a negative benefit. In a particular case it is not difficult for the analyst to decide how to treat costs of sullage removal when comparing different sanitation streams. For the purposes of this study, however, and because a more general comparison is required, a consistent assumption has been applied. Therefore, the costs in tables 3-1 through 3-11 include sullage disposal only if the sanitation system itself is designed to accommodate it. This is true of all the sewerage systems, all the septic tanks, and the Ndola and Newbussa sewered aquaprivies.

A final problem in preparing comparable cost figures for sanitation systems is the method to be used in gathering data. This study is statistically based, in contrast to a synthetic framework that develops an ideal model and tests the effects of varying assumptions. Both methods have their advantages and disadvantages. Because so little is known about the technology or costs of nonconventional sanitation systems, it was decided that a broadly based study involving many systems in many different settings would provide the best comprehensive frame for designing particular studies or, indeed, for selecting "typical" technologies and settings to proceed from in developing a synthetic model. The major disadvantage of a statistical approach, however, is that it is very difficult to identify the factors that cause increased or decreased costs because it is impossible to vary one factor at a time while holding all others constant. Cross-country comparisons can be misleading unless one is familiar with the background of the cases compared. For this reason, most technological comparisons are made within a single country—whenever possible, within the same community.

In one case, that of Malacca, a synthetic study was carried out to test with more precision the cost differential between sewerage and vacuum-truck cartage. In Gaborone, an excellent comparison of the costs of on-site systems was possible because of recent work carried out there under a project of the International Development Research Centre. It is expected that more cost-modeling exercises will be undertaken as routine feasibility studies expand to include nonconventional sanitation systems.

Field Results

The costs discussed below have been disaggregated in two ways, by function and by investment versus recurrent costs. In disaggregating by function, the categories used are on-site facilities, collection, treatment, and reuse. This distinction is made primarily because disaggregating by function allows a broad examination of the costs of repackaging components. For example, many treatment alternatives can be linked with a variety of collection systems, on-site facilities, or both. In addition, disaggregation by function is amenable to "value engineering" by its identification of the areas in which the greatest potential for cost savings exists. It also provides the financial analyst with a rough guide for determining the proportion of system costs that must be borne by the utility relative to the costs incurred directly by the household. The latter cost is a useful figure for estimating the willingness of the consumer to pay utility rates; this willingness will be based, in part, on the costs to the household of obtaining the private facilities that will enable it to make use of the utility's service.

The second type of disaggregation is the separation of capital and recurrent costs. The difference between technologies with high capital cost and high recurrent cost generally parallels that of capital-intensive versus labor-intensive technologies. This is because the investment costs of most systems are mainly in capital, and recurrent costs are mainly in labor. The distinction is made here between investment and recurrent costs —rather than between capital and labor—partly to emphasize the main cause of the difference and partly to stress the important institutional implications of managing a system with high recurrent costs.

Comparison of costs by technology

The single most useful figure for cost comparisons of technologies is the total annual cost per household (TACH), which includes both investment and recurrent costs (properly adjusted to reflect real opportunity costs and averaged over time by the AIC method). The TACH would, however, be misleading when applied to communal facilities or cases where several households share one toilet. In those instances, an adjusted TACH has been calculated by scaling up per capita costs by the average number of persons in a household.

Because both investment and recurrent costs must be included for a least-cost comparison, and because different technologies have different lifetimes, the TACH is an annuitized (or annual) figure. It should not, however, be interpreted as an amount of money to be spent annually for a particular technology. To illustrate this, consider the case of the pour-flush (PF) toilet with a mean TACH of $18.7. This figure is derived as follows:

	Cost (U.S. dollars)
Mean investment cost	70.7
Mean lifetime (years)	22.0
Mean annuitized investment cost	13.2
Mean annual maintenance cost	2.4
Mean annual water cost	3.1
TACH	18.7

The figure for mean annuitized investment cost is the weighted average of three case studies with opportunity costs of capital of 12, 20, and 20 percent and lifetimes of twenty, twenty, and twenty-five years, respectively. Although the TACH is $18.7, the actual cash expenditure (including water costs) is only $5.5 annually.

The TACHs obtained for ten technologies (arranged by ascending mean TACH) are summarized in table 3-1. Several summary statistics are shown because of a wide variation in the number of case studies and the range of costs.[11] Contrary to expectation, the technologies do not divide cleanly into community and individual systems when ranked according to cost. The most expensive technological group (with a TACH greater than $300) includes sewerage and Japanese and Taiwanese septic tanks. The middle-range technologies (those with TACHs between $150 and $200) are aquaprivies, sewered aquaprivies, and Japanese cartage. The low-cost technologies (those with TACHs less than $100) include both community systems (such as bucket latrines) and most individual systems. The divisions between high-, medium-, and low-cost technologies are fairly sharp, with large buffer areas available for upgrading systems. The fact that variations on septic tanks and vacuum-truck cartage appear in two categories indicates the potential for installing a low-cost facility at an early stage of development and improving its standard of service as development proceeds.

Within the low-cost group of technologies there is a fairly large variety of systems, ranging from aquaprivies and simple septic tanks to pit latrines and PF toilets. Vacuum-truck cartage (non-Japanese) and bucket cartage, with TACHs in the $35 to $65 range, fall in the middle of this group. The vacuum-truck cartage figures, however, are derived mostly from case studies

Table 3-1. *Summary of Total Annual Cost per Household (TACH) for Sanitation Technologies*
(1978 U.S. dollars)

Technology	*Observations (number)*	*Mean*	*Median*	*Highest*	*Lowest*
Low cost					
Pour-flush (PF) toilet	3	18.7	22.9	23.3	10.1
Pit latrine	7	28.5	26.0	56.2	7.6
Communal septic tank[a]	3	34.0	39.0	48.0	15.0
Vacuum-truck cartage	5	37.5	32.2	53.8	25.7
Low-cost septic tank	3	51.6	45.0	74.5	35.4
Composting toilet	3	55.0	56.2	74.6	34.3
Bucket cartage[a]	5	64.9	50.3	116.5	23.1
Medium cost					
Sewered aquaprivy[a]	3	159.2	161.4	191.3	124.8
Aquaprivy	2	168.0	168.0	248.2	87.7
Japanese vacuum truck cartage	4	187.7	193.4	210.4	171.8
High cost					
Septic tank	4	369.2	370.0	390.3	306.0
Sewerage	8	400.3	362.1	641.3	142.2

a. Per capita costs were used and scaled up by the cross-country average of six persons per household to account for large differences in the number of users.

in Korea and the island of Taiwan, which exhibit a degree of labor efficiency that might be difficult to replicate in other parts of the world. Figures for bucket cartage are mostly from Africa and represent poorly functioning systems that probably should not be replicated without upgrading. Thus, the TACHs of community systems in the low-cost group are likely to understate their cost of construction and operation in other countries. Of course, since all of the costs summarized in table 3-1 are derived from particular case studies, none can be considered an accurate representation of what it would cost to build a particular system in a different country.[12]

Cost comparison

It is useful to consider the overall variation of cost in different countries before making an examination of the cost data for each technology. The magnitude of the total variation is quite large, as is indicated in the last two columns of table 3-1. In nearly all cases the range (highest minus lowest) is nearly double the mean. In a statistical study of this type, such a wide variation is to be expected and does not present a major problem because the figures are meant to be descriptive rather than predictive. Even within a single country, cross-community cost differences were apparent when a single technology was found both in urban and rural areas. Further, the relatively wide margins between the groupings of technologies in high-, medium-, and low-cost systems indicates that the groupings are probably accurate, although the means may be 50 percent too low or too high.[13]

The total variation is caused in part by differences in the costs of basic inputs (such as labor) and in part by differences in the combination of inputs used (for example, labor-intensive versus capital-intensive treatment processes). To some extent, these two factors offset one another because a country with high capital costs, for example, would be expected to choose a less capital-intensive treatment process. For two of the systems, vacuum-truck cartage and septic tanks, the difference in the combinations of inputs seems to be very important because the case studies' costs exhibited a bimodal distribution, which could be directly traced to differences in the technologies employed in different locations. In no two case studies is the exact design of a system replicated; that is, no two pit privies are exactly alike. For most of the technologies, however, the variation in costs parallels the general price levels of the locations.

A sampling of the most important input costs is shown in table 3-2. A wide range is exhibited in three of the main inputs to sanitation systems: unskilled labor, water, and land. The sensitivity of system costs to changes in factor input prices is not easy to investigate in a comparative study such as this. The final section of this chapter, however, presents general conclusions on cost sensitivities.

Table 3-2. *Selected Input Costs and Conversion Factors for Sanitation Technologies*
(1978 U.S. dollars)

Location	Unskilled labor (daily)[a]	Water (per cubic meter)[b]	Land (per hectare)[c]	Capital (percent)	Conversion factors: Unskilled labor	Conversion factors: Foreign exchange
Botswana	1.80	0.38	100	10	0.7	1.00
Colombia	3.20	0.30	n.a.	12	0.3	1.00
Ghana	5.50	n.a.	65	12	0.8	1.75
Indonesia	1.80	0.11[d]	n.a.	20	1.0	1.00
Japan	10.50	0.85[d]	n.a.	10	1.0	1.00
Korea	4.00	n.a.	n.a.	14	0.8	1.12
Malaysia	3.40	0.35	200	12	1.0	1.00
Nicaragua	2.10	0.13	n.a.	20	0.5[e]	1.10
Nigeria	3.40	1.60	n.a.	12	0.8	1.15
Sudan	1.90	0.39[d]	100	16	1.0	1.25
Taiwan	3.95	0.40[d]	800	12	0.9	1.00
Zambia	4.00	0.70	65	12	0.6	1.25
Mean	3.80	0.36	222			
Median	3.40	0.39	100			
Range	8.70	1.49	735			

n.a. Not available.

Source: World Bank country economists and field consultants reporting on case studies. For more detail, see Richard Kuhlthau (ed.), *Appropriate Technology for Water Supply and Sanitation*, vol. 6, *Country Studies in Sanitation Alternatives* (Washington, D.C.: World Bank, 1980).

a. Market price in studied communities including benefit package where applicable.

b. Average incremental cost (AIC).

c. Estimated opportunity cost; collected in those cases where land costs were part of waste treatment.

d. Average of several community studies.

e. Unskilled rural labor only; for urban unskilled labor, conversion factor is 1.

Investment and recurrent costs

The distinction between investment and recurrent costs is an important one for both financial and technical reasons. A city or community with very limited present fiscal resources but with a good growth potential might find it impossible to raise the investment finance to build a system with large initial capital requirements, but it could build and maintain another system (with the same TACH) whose recurrent costs were relatively high. Conversely, a major city in a developing country that has access to external sources of funds might prefer to build an expensive system initially with the help of grant or low-interest loan capital and possibly reduce its need for recurrent funds.[14]

From the technical viewpoint, high recurrent costs generally stem from large operating and maintenance requirements. It may be unwise to opt for a system with high recurrent costs in those developing countries in which skilled labor is scarce or in which the management necessary to coordinate large numbers of unskilled workers does not exist. An offsetting benefit to this problem is that the employment benefits arising from a system with high recurrent cost (such as vacuum-truck collection) may be large enough to justify training (or importing) the necessary management skills.

The breakdown for investments and recurrent costs for the technologies studied is presented in table 3-3. There is no consistent relation between the overall cost of systems and their percentage of investment or recurrent costs. The two high-cost and two of the medium-cost technologies exhibit recurrent costs amounting to between 20 and 40 percent of TACH. The systems with the highest recurrent costs (as a percentage of the total) are in the low-cost group—namely, non-Japanese cartage and buckets, with 52 and 43 percent recurrent cost, respectively. The lowest percentage recurrent cost systems—pit privies, aquaprivies, and composting latrines—are in the low- and medium-cost groups.

This somewhat surprising lack of correlation is in part because of the nature of the figure for recurrent cost. Because economic—rather than strictly financial—costs are used in this study, a major item is included in recurrent cost that typically does not appear in engineering cost estimates: the water used to flush some systems. Although water for flushing is absolutely necessary for the proper operation of many systems (from sewerage to PF toilets), its cost is often ignored in engineering or financial studies that focus only on those costs incurred by the utility. In order to see how the inclusion of the cost of water for flushing would affect the breakdown of investment versus recurrent costs, separate calculations excluding water costs were made for those six systems that require water.[15]

The overall conclusion from table 3-3 is that nearly all of the sanitation systems are relatively high in investment, as opposed to recurrent, cost. Only in the case of non-Japanese cartage do recurrent costs represent more than half of TACH. In ten of the twelve systems (with the two varieties of septic tank and vacuum-truck cartage taken as separate systems), investment costs account for more than 60 percent of TACH. If costs of water for flushing are excluded from recurrent costs, as is done in table 3-4, only vacuum-truck cartage and bucket systems show recurrent costs of more than 30 percent.

There are several implications of this concentration in investment costs. One is that there is probably scope for external financing regardless of which technology is chosen by a particular city or community. High initial costs almost invariably require some sort of financial mechanism to smooth payments so that they are more in line with benefits delivered to (and paid for by) the consumers. A second implication is that, where funding constraints are binding, the size of the initial investment requirement may be the most important determinant of technological choice. There is relatively little scope for substituting a system of higher recurrent cost.

Table 3-4. *Percentage Investment and Recurrent Cost of Community Sanitation Systems*

	Percentage of total	
Technology	*Investment cost*	*Recurrent cost*
Sewerage	81	19
Sewered aquaprivy	84	16
Japanese vacuum-truck cartage	68	32
Other vacuum-truck cartage	48	52
Bucket cartage	57	43
Communal toilets	88	12

Note: Percentages are calculated excluding costs of water used in flushing.

In that sense, a distinction based on the relative importance of investment and recurrent costs of different systems becomes moot. Whereas sewerage and PF toilets both entail recurrent costs of about 30 percent of their respective TACHs, the important point is that the investment cost (per household) of the former is more than twenty times larger than that of the latter.

Considering only the community systems covered in this study, the distinction between investment and recurrent costs becomes more relevant. The three cartage systems are much more intensive in recurrent costs than are the water-carried systems (or even communal latrines) when water costs are excluded. The financial result of a system with high investment cost is relatively high fixed costs that must be met regardless of how much service is provided (or how many new connections are made). This can put a real financial

Table 3-3. *Average Annual Investment and Recurrent Cost per Household for Sanitation Technologies*
(1978 U.S. dollars)

				Percentage of total	
Technology	*Mean TACH*	*Investment cost*	*Recurrent cost*	*Investment*	*Recurrent*
Low cost					
PF toilet	18.7	13.2	5.5	71	29
Pit latrine	28.5	28.4	0.1	100	...
Communal toilet	34.0	24.2	9.8	71	29
Vacuum-truck cartage	37.5	18.1	19.3	48	52
Low-cost septic tank	51.6	40.9	10.7	79	21
Composting toilet	55.0	50.9	4.8	92	8
Bucket cartage[a]	64.9	36.9	28.0	57	43
Medium cost					
Sewered aquaprivy[a]	159.2	124.6	34.6	78	22
Aquaprivy	168.0	161.7	6.3	96	4
Japanese vacuum-truck cartage	187.7	127.7	60.0	68	32
High cost					
Septic tank	369.2	227.3	141.9	62	38
Sewerage	400.3	269.9	130.4	67	33

... Negligible.

a. Per capita costs were used and scaled up by the cross-country average of six persons per household to account for large differences in the number of users.

burden on the utility or municipality during the early years of such a system. It also means that the financial viability of the utility is extremely sensitive to the accuracy of the demand forecast. With systems having high recurrent costs (such as cartage), the response to slow growth in demand is delayed investment in new trucks and fewer new workers hired. With systems having high investment costs, however, there is little scope for reducing costs in response to reduced demand. This is perhaps not a major worry in cities that already have sewerage in some areas, for example, and are ready to expand their system. Here the demand for the service has already been tested. In cities of the developing world, however, where no such service already exists (and where the ability to pay for the necessary on-site investment is limited), it is extremely risky to choose a system that has high investment cost on the basis of hypothetical demand projections. In such a case, economies of scale are a two-edged sword.

On-site, collection, and treatment costs

The separation of TACH into its functional components is useful in determining where to direct the design effort in an attempt to reduce costs. For most of the individual systems, of course, all (or greater than 90 percent) of the cost is on-site. Thus, an investigation of the potential for cost reduction must concentrate on the on-site system components and the materials and methods used to produce and install them. The case study of Gaborone, Botswana, shows that between 40 and 60 percent of the TACH for pit latrines, composting toilets, and aquaprivies was for the superstructures, which were made of concrete blocks. If these experimental units had been built in the rural areas by villagers using local materials such as clay brick or straw matting, their cost could have been reduced significantly.

The functional breakdown of costs for the twelve systems is given in table 3-5. Even among the six community systems, on-site costs account for at least 45 percent of the total. Japanese and Taiwanese septic tanks have the highest on-site costs, over $300 per household annually. The size of the costs incurred by the household in total system costs shows the importance of finding ways for funding on-site facilities. The very low connection rates of many sewerage systems in developing countries (even when connection is a legal requirement) can probably be explained by the large household expenditure involved.

Two of the systems, sewerage and vacuum cartage, exhibit an interesting variety of cost patterns across the case studies. The sewerage costs for the eight cities covered are shown in table 3-6. There is a wide difference in on-site costs ranging from an average of about $300 per household annually for the Japanese systems to an average of just over $130 per household annually for the five systems in developing countries. This variation is caused by the more elaborate internal plumbing facilities that are found in middle-class Japanese homes and the high cost and relatively large amount of flushing water required by the Japanese systems.[16] The investment costs of collection for the sewerage systems do not fall into any clear groupings but vary with the terrain and population density of the

Table 3-5. *Average Annual On-site, Collection, and Treatment Costs per Household*
(1978 U.S. dollars)

Technology	*Mean TACH*	*On-site*	*Collection*	*Treatment*	*Percentage of total: On-site*	*Percentage of total: Collection*	*Percentage of total: Treatment*
Low cost							
PF toilet	18.7	18.7	···	···	100	···	···
Pit privy	28.5	28.5	···	···	100	···	···
Communal toilet	34.0	34.0	···	···	100	···	···
Vacuum-truck cartage	37.5	16.8	14.0	6.6	45	37	18
Low-cost septic tank	51.6	51.6	···	···	100	···	···
Composting toilet	55.0	47.0	···	8.0	85	···	15
Bucket cartage[a]	64.9	32.9	26.0	6.0	51	40	9
Medium cost							
Sewered aquaprivy[a]	159.2	89.8	39.2	30.2	56	25	19
Aquaprivy	168.0	168.0	···	···	100	···	···
Japanese vacuum-truck cartage	187.7	128.0	34.0	26.0	68	18	14
High cost							
Septic tank	369.2	332.3	25.6	11.3	90	7	3
Sewerage	400.3	201.6	82.8	115.9	50	21	29

··· Negligible.

a. Per capita costs were used and scaled up by the cross-country average of six persons per household to account for large differences in the number of users.

Table 3-6. *Annual Sewerage Costs per Household*
(1978 U.S. dollars)

City	On-site			Collection		Treatment		Total
	Investment	Recurrent	Flushing water	Investment	Recurrent	Investment	Recurrent	
Kyoto, Japan	166.1	41.3	126.4	88.9	12.1	147.1	59.4	641.3
Hannoh, Japan	146.0	45.5	112.8	58.5	13.3	96.0	89.4	561.5
Higashi Kurume, Japan	153.4	37.6	71.3	36.2	3.9	55.4	42.6	400.4
Khartoum, Sudan	89.2	...	32.3	174.3	8.5	255.0	12.8	572.1
Managua, Nicaragua	80.8	7.1	10.2	105.1	2.6	89.8	28.2	323.8
Ndola, Zambia	105.8	17.6	153.3	23.5	5.9	5.9	5.9	217.9
Malacca, Malaysia[a]	98.9	10.3	34.2	56.9	25.1	8.2	9.3	242.9
Gaborone, Botswana	61.4	...	11.0	40.9	6.6	16.2	6.1	142.2

... Negligible.
a. Based on a sewerage master plan.

cities. Recurrent costs of collection are uniformly low. In treatment costs there is an expected split between those with conventional plants (activated sludge or trickling filter) and those with ponds. The average treatment costs of the former are $175 per household annually, whereas those of the latter are less than $20 per household annually.

The costs from the case studies involving vacuum-truck cartage are shown in table 3-7. The major difference between the Japanese systems and the others is in the investment cost to the household. The collection vehicles used in Japan are more expensive than those used elsewhere, and labor costs for vehicle operation and maintenance are much higher. These two factors, however, are far outweighed by the very large differential in household facility costs. This has important implications for the upgrading of cartage systems. As long as the utility provides efficient and hygienic vacuum-truck collection, individual households have the option of improving their individual facilities as their income permits.

Controlled Comparisons

As mentioned previously, the major disadvantage of conducting comparisons of technology across locations is that it is difficult to draw conclusions about how particular technologies would compare in a given country or site. Analysis of a single location requires controlled tests. Fortunately, the present study did include selected cases in which various technologies were competing within a small geographic area. These cases still do not yield the sort of precision that could be obtained with purely synthetic examples because even adjacent areas are not identical. An offsetting advantage of using actual case data, however, is that these data do include the imperfections (for example, low use

Table 3-7. *Annual Vacuum Cartage Costs per Household*
(1978 U.S. dollars)

City	Population served (thousands)	Costs: On-site		Collection		Treatment		Total
		Investment	Recurrent	Investment	Recurrent	Investment	Recurrent	
Kyoto, Japan	1,462	92.5	18.5	6.1	35.3	15.3	4.1	171.8
Hannoh, Japan	56	113.3	22.7	7.5	43.2	18.7	5.0	210.4
Higashi Kurume, Japan	103	118.2	18.8	3.8	16.5	16.9	18.0	192.2
Tatayama, Japan	57	106.3	20.0	3.3	21.2	8.9	16.8	176.5
Keelong, Taiwan	342	9.6	2.2	1.9	12.2	3.9	2.4	32.2
Tainan, Taiwan	85	9.6	2.2	2.2	15.3	...	...	29.2
Pingtung, Taiwan	175	9.6	2.2	0.8	8.1	2.4	2.6	25.7
Chuncheon, Korea	141	20.9	6.6	0.1	5.7	5.0	8.1	46.4
Malacca, Malaysia[a]	95	13.5	7.8	3.9	19.9	7.3	1.4	53.8

... Negligible.
a. Based on a hypothetical system design.

of capacity or poor equipment maintenance) that might not be built into a model. Two controlled comparisons are discussed below: one between sewerage and cartage systems in the same cities and one between four on-site technologies and sewerage.

Sewerage versus cartage

Three of the Japanese communities studied were served by both sewerage and vacuum-truck cartage. In Kyoto and Higashi-Kurume, about 45 percent of the population are connected to public sewers and an equal number enjoy vacuum-truck collection. In Hannoh, nearly 60 percent are served by vacuum trucks, 15 percent by sewerage (with the rest using individual systems). The TACHs of the two systems in the three cities are as follows (TACHs are in U.S. dollars):

	TACH	
	Sewerage	*Cartage*
Kyoto	641.3	171.8
Higashi-Kurume	400.4	192.2
Hannoh	561.5	210.4
Average	534.4	191.5

In Kyoto, where sewerage is especially expensive (partly because of the high average incremental cost of water), cartage costs only about one-fourth as much per household. In the other two cities, cartage costs are about half those of sewerage.[17]

There is a growing demand on the part of householders in Kyoto for the sewer system to be extended to areas presently served by night-soil collection. Because the tabulation above shows that sewerage costs nearly four times as much as cartage, it might seem that people who can afford it value the increased convenience of sewerage at least as much as the difference in cost. But it is worth repeating that the costs developed in this economic comparison reflect real resource costs to the economy, not financial costs actually charged to households. In Japan, as in many other locations, the construction costs of sewers and treatment facilities are heavily subsidized by the national government. In addition, the city of Kyoto provides municipal loans at no interest for the installation of a flush toilet and indoor plumbing. In addition, the sewerage authority in Kyoto operates at a substantial loss (based on its sewerage revenues). In fiscal year 1976, subsidies from other city accounts represented 47 percent of the sewerage authority's total revenues. Thus, the financial cost of sewerage (and also of cartage) in Kyoto to the householder significantly understates its true economic cost.[18]

A more detailed controlled comparison between sewerage and vacuum-truck cartage was carried out for Malacca, a city of about 90,000 in Malaysia.[19] Currently the city is served by a combination of bucket latrines, septic tanks, PF toilets, and privies that directly overhang the river. The wastes from kitchen and bath are discharged to open, surface water drains. A sewerage master plan was prepared for the city in 1968, but—because of lack of money, potential technical problems stemming from a high water table, and community dissatisfaction with the proposed marine outfall—there has been no follow-up implementation of the study's recommendations. A Malaysian engineer who was familiar with the local conditions and history was asked to prepare an alternative master plan to serve the city with vacuum-truck collection and to compare the costs with those of the sewerage study (adjusted for inflation).

The annual costs of waste disposal per household for the two systems in Malacca are shown in table 3-8. Total annual sewerage costs are nearly five times greater than cartage costs. No social weighting for employment benefits has been used in calculating these costs, but the cartage system would employ more than twice as many people as the sewerage system, including 100 general laborers (compared with 14 for sewerage).

On-site systems

A controlled cost comparison of on-site systems is possible with the results of the study of Gaborone, Botswana. The International Development Research Centre sponsored an experimental latrine program in Botswana to build and monitor a variety of on-site designs. The four designs that performed best were costed for inclusion in this study. While the costs for all systems appear high relative to those for similar systems in other countries, this should not affect the relative comparison of technologies. The high costs are

Table 3-8. *Comparative TACHs of Sewerage and Vacuum-truck Cartage in Malacca, Malaysia*
(1978 U.S. dollars)

TACH	*Sewerage*	*Cartage*
On-site		
Investment	98.9	13.5
Recurrent	43.5[a]	7.8
Collection		
Investment	56.9	3.9
Recurrent	25.1	19.9
Treatment		
Investment	8.2	7.3
Recurrent	9.3	1.4
Total	242.9	53.8

a. Includes $34.2 for water used in flushing.

because of the pilot nature of the project, the difficulty of obtaining even simple inputs (such as cement) locally, and some overdesign (particularly in the superstructure) of the systems.

The results of the costing analysis for ventilated improved pit (VIP) latrines, aquaprivies, double-vault composting (DVC) latrines, and Reed Odorless Earth Closets (ROECs) in Gaborone are shown in table 3-9. To enable a better comparison with the cost of sewerage in Gaborone, the cost of substructures alone are also shown. On a household basis, the VIP and the ROEC are by far the cheapest. The substructure cost of the DVC latrine is about 80 percent more. The aquaprivy cost (substructure) is more than double that of the VIP or ROEC, whereas sewerage costs are almost seven times higher.

No analysis of the benefits derived from the compost eventually available from the DVC was possible because all experimental units were recently constructed. Design parameters suggest that the DVC would require emptying only at five-year intervals, so that the amount of compost available (per household annually) is likely to be small. A firm analysis of the benefits from composting cannot be undertaken until more operational experience is available. It is unlikely, however, that such benefits would affect the net cost ranking of these alternatives.

The conclusions from these three exercises in controlled costing are in line with those of the cross-country, comparative analyses of technologies. Sewerage costs are at least twice and generally four to five times as large as those of well-run, vacuum-truck cartage systems. On-site technologies can effect even larger savings, particularly if superstructure costs can be kept low.

Table 3-9. *Comparative TACHs of On-site Systems and Sewerage in Gaborone, Botswana*
(1978 U.S. dollars)

Technology	*TACH*	*Annual substructure cost per household*
Ventilated improved pit (VIP) latrine	56.2	21.3
Reed Odorless Earth Closet (ROEC)	56.2	21.3
Double-vault composting (DVC) latrine	74.6	38.6
Aquaprivy	87.7	50.6
Sewerage	>142.2[a]	142.2

a. Superstructure costs are included in the house construction.

Benefits from Reuse

As discussed earlier in this chapter, it is assumed in this study that the major benefits of sanitation systems are related to health and convenience and therefore cannot be meaningfully quantified. Some of the technologies studied, however, provide economic benefits in the form of fertilizer or biogas, to which a monetary value can be assigned.[20] One of the original aims of this study, in fact, was to determine the scope for offsetting sanitation costs with reuse benefits.

Unfortunately, it has been very difficult to locate in developing countries working examples of human waste disposal systems with a sizable reuse component. A few of the sewage treatment systems produce small amounts of methane from their digesters, and this is used for heating. There is some demand from orchard farmers in Korea for the night soil collected by vacuum truck, but the municipality makes no effort to set up a delivery system or to charge a market-clearing price. The composting latrines built in Botswana are too new to yield useful data on reuse. All except one of the biogas units observed ran on animal, rather than human, waste. In short, although there is much experimental and theoretical information on the economic potential of reuse technologies, there is a dearth of empirical data on actual experience.[21]

All of the significant reuse technologies found in this study were located in the Far East. Biogas plants were found at the household level on the island of Taiwan and in Korea. Municipal systems involving reuse of human excreta as an input into agriculture and aquaculture were found on the island of Taiwan and, to a lesser extent, in Indonesia. In none of these cases was the reuse element developed to its full potential through marketing analyses or optimal pricing strategies. The cases described below, therefore, should not be taken as examples of how much (or, more accurately, how little) reuse benefits can affect the economics of sanitation.

Biogas

There were about thirty family-size biogas units in operation in one of the communities on the island of Taiwan studied in 1977. Each biogas unit consisted of a 6-foot diameter, excavated digester with an inverted steel lid that floated up and down on a water seal. The methane generated was transported to the kitchen through a pressure hose connected to the outlet pipe at the top of the inverted lid. The digester was emptied twice a year, and the sludge was sold to neighboring farmers. All of the digesters studied ran on a mixture of human and animal wastes. The usual input to a unit was the night soil from five persons and the manure from five pigs. This input loading produced sufficient gas for cooking purposes all year for a family of five, a replacement for the 20-kilogram cylinder of liquid petroleum gas formerly purchased each month. The net cost of a typical biogas unit on the island of Taiwan is shown in table 3-10.

This net cost does not represent the full cost of the total system of hog raising–excreta disposal–biogas production. It has been developed within the more limited framework in which the "with and without" cases are defined as with and without the latrine equipped with biogas digester. Thus, the cost of hog feed and upkeep is not included, nor is the benefit from the sale of the animals. For purposes of comparison with costs of other sanitation systems, this is the appropriate method to employ. For a complete project appraisal, however, it would be inadequate. This point was demonstrated on the island of Taiwan by the marked decline in the number of household biogas units in the last five years because of the large increase in the price of animal feed, which has made hog raising uneconomic.

In addition, although the net cost of this sanitation system is attractively low compared with that of the other units considered above, its initial investment cost is very high. In a subsistence economy, large investment costs may present an insurmountable obstacle to the adoption of a low-cost system unless subsidized loan capital can be made available or less expensive designs developed. The requirement for such large volumes of animal waste is also likely to exclude the lowest income classes, who generally do not own animals (or land on which to build the digester). Furthermore, that this biogas unit is economically attractive on a household scale does not imply that it would be advantageous on a community scale. Aside from the technical questions of the economies of scale of the digester itself, the collection and transportation of human and animal wastes to a single point and the subsequent redistribution of gas would involve large capital outlays and operating requirements that are avoided by a single-family unit located in the courtyard of the house.

Table 3-10. *Net Cost of Household Biogas Unit, Island of Taiwan*
(1978 U.S. dollars)

Item	*Total cost*	*Annual cost*	*Lifetime (years)*
Cost			
Construction[a]	236.0	31.6	20
Land (for 15 square meters)	348.0	41.8	Infinite
Annual desludging	16.6	16.6	—
TACH		90.0	
Benefit			
Biogas (12 cylinders of liquid petroleum gas at 6.25)		75.0	—
Sludge sales (2 carts)		11.0	—
Net annual cost per household		4.0	

— Not applicable.
a. Includes household latrine facilities.

A second case of household biogas production was observed in Korea. There, the family claimed to be using only human excreta and kitchen wastes to stock the unit. It produced sufficient gas to satisfy all of the cooking needs during nine months of the year. Insufficient cost data were available, however, to permit a calculation of net cost.

Agricultural reuse

Reuse of composted night soil as fertilizer is also practiced at the household level in rural areas of Korea. The large size of household pit privies in two rural villages studied was puzzling until it was discovered that the farmers deposited the animal wastes from nearby cattle pens into the pits and then allowed the entire quantity to "compost" over a six- to twelve-month period before spreading it on the vegetable fields and orchards. Based on the Korean government's imputed cost of such organic fertilizer, the composting operation yielded the farmer an annual net benefit of $37 on an annual cost of $34. These figures do not include any cost for the farmer's time in digging out the latrine and transporting the compost to the field. Nonetheless, they indicate the potential for agricultural reuse at the household level in rural areas.

At the community level, again, very few data are available. In Chuncheon, Korea, some of the night soil collected by vacuum truck is sold to farmers (before treatment) for about $7.00 per truck (or $3.50 per cubic meter). At this rate, demand is sufficient to absorb about half of the night soil produced by the city. Because the demand is seasonal, however, the night-soil treatment plant, which was designed for peak volumes, operates inefficiently during the spring and summer months. There is very little net benefit, therefore, to the city (about 3 percent of the cost on an annual basis) from the sale of untreated night soil, and the health hazards to the farmer from handling it are probably considerable. If a simple composting treatment plant had been built instead of the two-stage digester, a market for treated night soil might have developed that would have minimized sanitation costs to the community while providing a safe and valuable product to nearby farmers.

Aquacultural reuse

The best case study involving community-scale reuse was conducted in Tainan on the island of Taiwan. Both public and private night-soil collectors operate there, and untreated night soil is sold primarily to fish farmers. The private collectors work only during the ten months of the year in which there is a demand for night soil. The public system, of course, operates year-round and is able to sell about 80 percent of its total collection. The public system charges $0.65 per ton plus $0.57 per kilometer for transportation costs, whereas the private collectors charge $7.00 per ton inclusive of transportation (most trips were less than 10 kilometers).

No investment or operating costs were available on the private collectors. The TACH of the public system was $28.85, and the sale of night soil during the ten months of the year yielded $1.28 on a household basis. Because the private operators presumably earn a positive income on their operations, the public system must either incur significantly higher costs or charge too little for its product, or both.

Financial Implications

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—that is, 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 change dramatically. Whereas economic costs are based on the physical conditions of the community (for example, its abundance or scarcity of labor, water, and so forth) and are therefore quite objective, financial costs are entirely subject to interest-rate policy, loan maturities, central government subsidies, and the like. The financial cost of a sewerage system for a community can be zero if the central government has a policy of paying for such systems out of the general tax fund.

To promote the economically efficient allocation of resources, financial costs should certainly reflect economic costs as closely as possible, given the government's equity goals and the degree of distortion in other prices in the economy. This correspondence could be accomplished with sewerage, for example, by setting a surcharge on the water bills of connected consumers that is equal to the AIC of sewerage per cubic meter of water consumed.[22] In the case of most on-site systems, the consumer would pay to construct the original facility (either initially or through a loan at an interest rate reflecting the opportunity cost of capital) and then pay a periodic sum to cover the facility's operation and maintenance expenses (if any). In cases such as these, the financial cost would be identical to the economic cost except for any taxes and shadow pricing of inputs that must be purchased in the market.[23] To the extent that they account for a significant part of total economic costs, financial costs may be above or below economic costs.

In deriving financial costs in any particular case, it is necessary for the analyst to consult with officials of the central and local government 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 costs 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 permit adequate health is more than a small part of the household income of the lower income consumer (say, 5-10 percent), then the central or local government should attempt to subsidize its construction to make the facility affordable. If, however, some consumers wish to have better or more convenient facilities, they should pay the additional cost themselves. Similarly, if more affluent communities decide that, beyond meeting basic health needs, they wish to safeguard the cleanliness of their rivers or general environment by building a more expensive sanitation system, then they should pay for that system either through direct charges to users or through general municipal revenues. Because the majority of the poorest people in most countries live in rural areas, it is usually not appropriate to subsidize urban services from national tax revenues.

Because financial costs are dependent upon policy decisions, it is not possible to present comparable financial costs of the various technologies in the same way that economic costs can be developed. It is, however, possible to use the economic costs to derive total investment costs per household that will provide a basis for the financial comparison of alternatives. The other useful figure to be extracted from economic costs is the annual recurrent cost (with water costs shown separately), which will give an indication of periodic financial requirements.

The financial requirements for the various low-, medium-, and high-cost systems examined are given in table 3-11. The first column shows the total investment cost (including on-site, collection, and treatment facilities) divided by the number of households to be served. For the individual household systems (such as pit latrines), the investment cost is simply the total cost of constructing the facility. For the community systems, it is the total cost divided by the design population (number of households). Thus, for those facilities that exhibit economies of scale, such as sewage treatment plants, this figure will understate the real financial requirements during most of the early years of operation. Note that because investment costs do not reveal anything about the lifetime of facilities they should not be used to make judgments about least-cost alternatives. They are presented only to indicate an order of magnitude of the initial financial expenditure necessary for the various systems.

The monthly recurrent cost per household (second column of the table) is the sum of recurrent costs for on-site, collection, and treatment facilities excluding costs for water used in flushing, which are presented separately in the third column of table 3-11. Because water charges vary so much from one community to another (both for economic and financial reasons), their absolute level is less relevant than their relation to other recurrent charges. In addition, it was not possible to use market prices for water in the various communities because of different charging systems and, for some cases, lack of data.

It is difficult to draw conclusions from the financial requirements because of the reasons of noncomparability mentioned above. Some standard loan terms, however, were assumed in order to derive one possible set of financial costs (shown in the fourth column of table 3-11). Because the length of loans is generally related to the life of facilities financed, loan periods of five, ten, and twenty years were used for the low-, medium-, and high-cost systems, respectively. An 8 percent interest rate (well below the opportunity cost of capital in most countries) was used as a representative interest charge for loan funds to a utility. Financial affordability can be roughly tested by comparing financial costs to household income (see the table's fifth column). Average income per capita in the low-income countries (where the bulk of the water and sanitation deficiencies exists) was about $180 in 1978. With an average of six persons per household, this yields a monthly household income of $90. All of the medium- and high-cost systems have monthly costs that amount to over 10 percent of income and, thus, are probably outside the range of affordabil-

Table 3-11. *Financial Requirements for Investment and Recurrent Cost per Household*
(1978 U.S. dollars)

Technology	*Total investment cost* *(1)*	*Monthly recurrent cost* *(2)*	*Monthly water cost* *(3)*	*Hypothetical total monthly cost*[a] *(4)*	*Percentage of income of average low-income household*[b] *(5)*
Low cost					
PF toilet	70.7	0.2	0.3	2.0	2
Pit latrine	123.0	...	...	2.6	3
Communal toilet[c]	355.2	0.3	0.6	8.3	9
Vacuum-truck cartage	107.3	1.6	...	3.8	4
Low-cost septic tank	204.5	0.4	0.5	5.2	6
Composting toilet	397.7	0.4	...	8.7	10
Bucket cartage[c]	192.2	2.3	...	5.0	6
Medium cost					
Sewered aquaprivy	570.4	2.0	0.9	10.0	11
Aquaprivy	1,100.4	0.3	0.2	14.2	16
Japanese vacuum-truck cartage	709.9	5.0	...	13.8	15
High cost					
Septic tank	1,645.0	5.9	5.9	25.8	29
Sewerage (design population)	1,478.6	5.1	5.7	23.4	26

... Negligible.

a. Assumes that investment cost is financed by loans at 8 percent over five years for the low-cost systems, ten years for the medium-cost systems, and twenty years for the high-cost systems.

b. Assumes that average annual income is $180 per capita, with six persons in a household.

c. Based on per capita costs scaled up to household costs to account for multiple household use in some of the case studies.

ity without further subsidy. Sewerage and the Japanese and Taiwanese septic tanks have recurrent costs that alone are over 10 percent of income, even if initial facilities could be provided free of charge by the government. For most of the other systems, affordability hinges on the arrangements that can be made to subsidize investment costs from other revenue sources. Such arrangements, however, are probably not replicable on a wide scale. Furthermore, average figures of per capita income should not be relied upon without a recognition of their limitations in countries in which much of the economy is nonmonetized. In addition, many developing countries in Africa and Asia have per capita incomes that are less than the average of the low-income group used here, and, in all of the countries, more than half of the population earns less than the country average.

Conclusion

It may be useful to summarize some broad conclusions from this review of cost data. Precise calculations of the sensitivity of system costs to changes in particular parameters are impossible to generate within the framework of an empirically based study such as this. Yet it is possible to discern areas of relatively greater and lesser importance.

The two most outstanding influences on total household costs are factors that have often been ignored in engineering analyses: on-site household costs and the costs of water used for flushing in water-carried systems. The former is important in all systems and, in the cases studied, never accounted for less than 45 percent of TACH. The latter is most important for sewerage and septic tank systems. When the economic cost of water is high, the payoff from designing systems with low requirements of flushing water is large.[24]

A further implication relates to those aspects of sanitation systems that do not significantly influence costs but can make a big difference in benefits. Two components of individual systems—ventilation stacks and water seals—aid greatly in reducing odors and fly breeding without adding significantly to system costs. In one of the Latin American case studies, it was found that people were very concerned about the color of the floors of their latrines. Although this preference is an aesthetic matter without technical importance, it may make the difference between a facility that is kept clean and is regularly used and one that is not. In another case the latrine designers, in an effort to cut costs, had used precut sheets of zinc for the superstructure siding. This meant, however, that the siding did not reach all the way to the floor—a design flaw that provided easy access for rodents and scorpions during the night and embarrassed users (whose feet could be seen while they used the latrine, a matter of sensitivity in this culture). Such unimportant details from the technical viewpoint are often highly significant if health and aesthetic benefits (both of which generate a willingness to pay on the part of the user) are to be fully realized.

A final caution is appropriate for the interpretation of the costs developed by these case studies. In very few cases were the systems optimally designed. This point has already been made with respect to the overdesigned superstructure of the Botswana latrines and the reuse components found in the East Asian countries. It is also true of the sewered aquaprivies in Zambia (which fed into collectors of conventional size designed for a full sewerage system) and most of the other cases. Nevertheless, the broad ranking of technologies, the patterns of cost sensitivity, and the method used to arrive at appropriate figures for a least-cost comparison are all believed to have general applicability.

Notes to Chapter 3

1. Variations of this calculation include the internal rate of return and the net present value. For a discussion of the set of conditions under which each is appropriate, see Lyn Squire and Herman G. van der Tak, *Economic Analysis of Projects* (Baltimore: Johns Hopkins University Press, 1975), pp. 39–43.

2. Ibid.

3. H. Shipman and others, *"Measurement of the Health Benefits of Investments in Water Supply,"* Public Utility Note 20 (Washington, D.C.: The World Bank, Transportation, Water, and Telecommunications Department, January 1976; processed).

4. See Squire and van der Tak, *Economic Analysis of Projects*, pp. 99–132, for a description of the data requirements and methods of computing conversion factors.

5. For example, in one Islamic country market interest rates are set by law at 3 percent, whereas the opportunity cost of capital has been estimated at 16 percent. With such a wide discrepancy, it is very likely that the least-cost alternative using the market discount rate would be much more capital intensive than that selected by an economic least-cost analysis.

6. This percentage is based on data from developed countries, which show that the water used to flush toilets is around 40 percent of total domestic water use (excluding garden watering).

7. See R. J. Saunders, J. J. Warford, and P. C. Mann, *Alternative Concepts of Marginal Cost for Public Utility Pricing: Problems of Application in the Water Supply Sector*, World Bank Staff Working Paper, no. 259 (Washington, D.C.: The World Bank, May 1977).

8. This degree of risk can be explicitly built into the alternative selection process. Suppose technology *A* yields a net present value of 100 and technology *B* one of 90, given the demand forecast. There is a 30 percent probability that the forecast is too high and a 10 percent probability that it is too low. If it is too high, technology *A*'s net present value drops to 30 because of its large unused capacity during the early years, whereas technology *B* can be modified to cut costs so that its net present value falls only to 70. If demand is too low, *A*'s net

present value falls to 90 and *B*'s falls to 85. The weighted average, or expected value (E), of the net present value of the two technologies can be calculated as follows:

$$E_A = 0.3(30) + 0.1(90) + 0.6(100) = 78.0$$

$$E_B = 0.3(70) + 0.1(85) + 0.6(90) = 83.5.$$

Given the uncertainty attached to the demand forecast, technology *B* should be selected because the expected value of its net present value is higher than that of technology *A*. If the demand forecast were certain, technology *A* would have the higher net present value.

9. The environmental cost of depositing sullage into nearby watercourses must, of course, also be assesssed. The limited information available on the composition of sullage wastes suggests that its health hazard is low. This should also be assessed, however, for the site in question.

10. The development of low-water-use appliances, such as showers, is a very promising means of realizing sanitation cost savings. Reducing the amount of sullage water to be disposed of not only saves water but also extends the range of applicability for on-site disposal systems.

11. All costs presented in this chapter are in 1978 prices and U.S. dollars. For price and foreign exchange conversion factors for each country studied, see Richard Kuhlthau (ed.), *Appropriate Technology for Water Supply and Sanitation*, vol. 6, *Country Studies in Appropriate Sanitation Alternatives* (Washington, D.C.: The World Bank, 1980).

12. The anomalies introduced by aggregating across countries are illustrated by a comparison of the TACHs of the pit latrine and PF toilet in table 3-1. The mean cost of the former in the seven cases studied was higher than that of the latter in its three case studies. Yet it is clear that, on any one site, a pit latrine would be cheaper than a PF toilet because of the extra components and water required for the latter.

13. The rankings within the groups should not be taken too seriously, however. For example, the mean TACH of sewered aquaprivies is lower than that of nonsewered aquaprivies, but this is because of the very high cost of the Sudanese aquaprivy, which is nonsewered.

14. Note that this would not be an *economically* efficient solution because the opportunity cost of capital does not depend on the source of the funds or the terms of a particular loan package.

15. As would be expected, those systems requiring the most flushing water are most affected by the change. The recurrent cost component of sewerage systems drops from 33 to 19 percent, whereas that of septic tanks falls from 36 to 24 percent.

16. Twenty liters per flush compared with 8–15 liters in the other countries.

17. In all three cities the night soil from the cartage systems is treated by dilution and transferred to the sewage treatment plant. It is likely that cheaper treatment methods could be used in cities without sewerage systems.

18. See chapter 6 for a discussion of the effect of such policies on the choice of appropriate technologies.

19. We are indebted to Mr. Ng Kin Seng for this comparison. A summary of his report is included in Kuhlthau (ed.), *Country Studies*.

20. Other potential reclamation benefits include stock and garden watering with sullage and irrigation with sewage.

21. The obvious exception to this statement is the experience of China, but scientific documentation of Chinese experience is rare, and it was not possible to include first-hand observation in this study. Many data are also available on biogas production in India, but most units use animal instead of human excreta.

22. Suppose, for example, that the AIC of sewerage is $1.00 per cubic meter of sewage collected and treated. Because water rather than sewage is metered, this AIC must be related to the water consumed. If, for a given city, sewage flows are 75 percent of water consumption, then the sewerage surcharge should be $0.75 per cubic meter of water consumed.

23. Note that the shadow price of capital may be reflected in the financial cost by using it as the interest rate at which money is loaned to construct facilities. If market rates are lower, however, the consumers will presumably borrow the money elsewhere and pay for the new facility immediately. Shadow rates for labor and water (the other important inputs in this analysis) cannot be incorporated into financial costs if the consumer pays for them separately.

24. The savings would be even larger if the improved designs for facilities led to the redesign of water distribution networks.

4

Public Health Aspects

IMPROVED COMMUNITY HEALTH is generally considered the major benefit of improved sanitation. As the discussion in the previous chapter has indicated, however, it has so far been impossible to determine precisely how much improvement in health in a given community can be attributed directly or indirectly to a sanitation improvement. Even if a figure for the health improvement could be agreed upon (for example, x fewer man-days of sickness annually), it is very difficult to assign a meaningful economic value to it. Much of the illness without the sanitation improvement would have been borne by children and others unemployed in the monetary sector. The noneconomic value to society of their improved health may be equal to that of an employed adult, but the economist has no way of quantifying such a nonmarket value. Moreover, of those man-days of illness incurred by the employed population, some (perhaps all) work is probably made up at no cost to society during the days following absence because of illness. To use an entire daily wage to value saved man-days of illness is almost certainly an overestimate. These inherent limitations of the health sciences in quantifying the effects of environmental changes on community disease profiles, and of economics in quantifying benefits that have no market value, combine to frustrate the measurement of health benefits.

Fortunately, the measurement of benefits is not the primary objective of improved sanitation; achieving the benefits is. If funds are inadequate to build and maintain the elaborate sewerage systems known to provide all these benefits, then it is essential to choose the alternative technology that *will* maximize the health benefits achieved with the available funds. This effort requires a more precise analysis of the relations between disease and sanitation than has been attempted in the past. Toward this end, consultants from the Ross Institute of Tropical Hygiene of the London School of Hygiene and Tropical Medicine were contracted, as part of this study, to focus specifically on the transmission process of excreta-related diseases and to investigate the relation of the various sanitation technologies described in chapter 2 to this process.[1] They have developed an environmental classification of excreta-related infections that, together with a basic understanding of the epidemiological factors important in disease transmission, should enable the planner and engineer to maximize the health benefits of whatever technology is chosen. The means of doing so include both the incorporation of specific features that inhibit disease transmission in the design of sanitation facilities and the supplementation of "hardware" with carefully directed educational campaigns.

Water and Health

Although the primary concern of the present study is sanitation, the relation between water and health should be kept in mind.[2] Water is important to health in two ways: contaminated water or insufficient amounts of water for personal hygiene can be a direct cause of disease; and the disposal of sullage (wastewater or greywater, see chapter 2, the section "Sullage Disposal") can, theoretically, serve as a transmission vehicle for some kinds of disease. For these reasons, not only poor water quality, but also too little and too much water consumption, present problems.

Available evidence indicates that most of the health benefits from safe water are attainable at service levels of 30–40 liters per capita daily on site. These service levels will provide protection against the range of water-related diseases and are adequate for the personal hygiene that will lead (with health education) to a lowered incidence of diarrheal disease and skin and eye infections. For the latter group, access to water is more important than its microbiological or chemical quality. In addition, concentrations of chemicals in drinking water in developing countries sometimes exceed the published standards or guidelines, which were developed in industrial countries. For example, groundwater in southern Africa containing several hundred milligrams of nitrate per liter is used for domestic supply, even though the concentration is an order of magnitude greater than the 45 milligrams per liter of the World Health Organization (WHO) standard. This standard was developed in industrial countries to eliminate the risk of methemoglobinemia ("blue baby syndrome") in bottle-fed infants, but may be less applicable in areas where infants are breastfed.

The fecal hazard of sullage has yet to be demonstrated. Crude estimates—based on data from the United States and assuming a high value of 150 liters per capita daily of sullage—indicate that per capita discharges of the indicators of bacterial pollution, fecal coliforms and fecal streptococci, in sullage are 10^6 and 10^5 bacteria per day, respectively.[3] Corresponding per capita discharges in feces are approximately 10^{10} for fecal coli and 10^9 for fecal streptococci, some four or five orders of magnitude greater than those for sullage. This means that, even though ratios of pathogens to indicators may be higher for sick people than for healthy ones, relative risks of infection from night soil or sewage are four or five orders of magnitude greater. This is consistent with the results of the inquiry into possible differences in health profiles between people living in areas served by sewers and in adjacent areas with night-soil collection and sullage discharge to surface drains (reported in chapter 2).

Some concern has been expressed over a possible contribution of sullage to increased populations of the *Culex pipiens* mosquito, which breeds in polluted water and is a vector of filariasis. The potential importance of sullage to mosquito breeding is determined by environmental factors in which low aridity (see maps 7-9, chapter 2) and local soil permeability would permit the water to remain on the surface long enough to permit mosquito breeding. Where there are extended periods of relative drought (see maps 4-6), surface impoundments of sullage could contribute to extending periods during which mosquitoes normally breed.

In sum, although disposal of large amounts of sullage resulting from high water service levels may be provided by sewerage in densely populated areas, in areas of lower water consumption or lower population density the problem of sullage is one of lower priority.

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 thence eventually reach others. These are 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 practices of human excreta disposal. A number of infections for which both man and other animals serve as a reservoir, however, are included.

Second, excreta relate to human disease because their disposal sometimes encourages the breeding of insects. These insects may be a nuisance in themselves (flies, cockroaches, mosquitoes); they may mechanically transmit excreted pathogens 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).

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 group of the population involved in transmitting an infection shows little or no sign 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 output of schistosome eggs in feces and urine reaching water from a human population may be produced by children five to fifteen years old. Many of these children will show minimal signs of disease; conversely, middle-aged people 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 critical 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, the concepts can be represented thus:

$$\text{EXCRETED LOAD} \rightarrow \begin{bmatrix} \text{Latency} \\ \text{Persistence} \\ \text{Multiplication} \end{bmatrix} \rightarrow \text{INFECTIVE DOSE}$$

There is wide variation in the excreted load 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 case may pass 10^{13} vibrios per day.

Where large numbers of organisms are being passed in the feces they can give rise to high concentrations in sewage. Thus, even in England, where water use is relatively high and salmonellosis relatively rare, raw sewage may contain 10^4 salmonellae per liter. At these concentrations, removal efficiencies of 99 percent in conventional sewage treatment works will still leave 10^2 pathogenic organisms per liter in the effluent, and the implications of these organisms for health will depend upon their ultimate disposal, their ability to survive or multiply, and the infective dose required.

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 infective 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. In particular, infections that have a considerable latent period are largely risk free in areas where night soil is being carted by vacuum truck, whereas the others constitute a major health hazard in fresh night soil. Therefore, in the environmental classification presented below the first two categories (in which no latency is observed) are separated from the remaining categories (in which a definite latent period occurs).

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.

A pathogen that persists outside the body only for a very short time needs to find a new susceptible host rapidly. Hence, transmission cannot follow a long route through sewage works and the final effluent disposal site back to man, but rather will occur within the family by transfer from one member to another as a consequence of poor personal hygiene. More persistent organisms can readily give rise to new cases of disease farther afield, and, as survival increases, so also must concern for the ultimate disposal of the excreta.

Though 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 pathogens are being shed in the excreta (which is relatively easy to determine) and the infective doses for man (which is extremely difficult to discover).

Under some conditions, certain pathogens will multiply in the environment. 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 (for example, *Salmonella* on food) or of the multiplication by trematode worms (the parasitic flatworms, including flukes) 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.

In principle, from a knowledge of the output of pathogens in the excreta of those infected, the mean infective dose, and the extractive efficiency of the excreta treatment process, simple calculation should enable one to assess risk. In practice, disease transmission is much less predictable than this because of the variable infective dose of most pathogens and the uneven distribution of infection in the environment. Whereas the minimal infective dose for some diseases may be a single organism, or very few, the doses required in most bacterial infections are much higher. Data bearing on this are very hard to acquire, since they involve administering a known dose of a pathogen to a volunteer. Information is scanty and is generally concerned with doses required to infect, say, half those exposed, rather than a minute proportion, at a single exposure. The volunteers have usually been well-nourished adults from nonendemic areas. Such results have to be applied with great caution (if, indeed, they can be applied at all) to malnourished children continuously exposed to infection.

Host response is important in determining the result of an individual's 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 and 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 significant effect under these circumstances by reducing the likelihood of an epidemic and, should one ever occur, its magnitude.

By contrast, if transmission is very high the population will be repeatedly exposed to an 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. The infection will always be present and is described as endemic. Under these conditions much transmission is ineffective because of human acquired immunity, and reduced transmission as a result of improved sanitation will only delay the date of infection until later in life. Large sanitary improvements will either render the infection rare or, if the disease was originally highly transmitted, make it an adult disease. Examples are typhoid, which can be completely prevented in the community by adequate management of excreta and of water supplies, and poliomyelitis virus infection, which requires extreme hygienic precautions to prevent. In practice, improved sanitation increases the disease problem by deferring infection to an age where its clinical course is more severe.

Consequences of a juvenile age-prevalence are that not only do children suffer chiefly from the diseases, but also that they are the main sources of infection, so that the most important need for better community excreta disposal is among young children, the group perhaps least inclined to use any facilities that may be available.

Some excreted diseases are infections exclusively or almost exclusively of man, but many involve other animals either as alternatives to man as host or as hosts of other stages in the life cycle. In the case in which wild or domestic vertebrate animals act as alternative hosts, control of human excreta is not likely to achieve complete prevention of the infection. Alternatively, if the infection under consideration needs an animal host for some intermediate stage, but also requires man, then the control of human excreta can be very effective in controlling the disease. Some excreted helminthic infections that have intermediate aquatic hosts fall into this category. These will be controlled if: excreta are prevented from reaching the intermediate host; or the intermediate hosts are controlled; or people do not eat the intermediate host uncooked or do not have contact with the water in which the intermediate host lives (depending on the particular life cycle).

Environmental Classification of Excreted Infections

The list of human pathogens in excreta given in table 4-1 is useful only insofar as it shows that the variety of pathogens is wide 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 that groups excreted pathogens according to common transmission characteristics is much more helpful in predicting the health effects of sanitation improvements and in understanding the health aspects of excreta and sewage treatment and reuse processes. The environmental classification presented below distinguishes six categories of excreted pathogens (see also table 4-2).

Category I

These are the infections that have a low infective dose ($<10^2$) and whose pathogens are infective immediately on excretion. These infections are spread very easily from person to person wherever personal and domestic hygiene are low. Therefore, it is likely that changes in excreta disposal technology will have little, if any, effect on the incidence of these infections if the changes 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 most important aspect of excreta disposal for the control of these infections is the provision of a hygienic toilet (of any kind) in the home so that people have somewhere to deposit their excreta. What subsequently happens to the excreta (that is, the means of transport, treatment, and reuse) 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 effect. However, categories I and II merge into each other and form a continuum (see below).

Category II

The infections in this category are all bacterial. They have medium or high infective doses ($>10^4$) and so are less likely than category I infections to be transmitted by direct person-to-person contact. Their bacteria 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 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 are waste treatment and reuse practices. Changes in excreta disposal and treatment practices alone may reduce the incidence of some infections such as cholera and typhoid but are unlikely to be as effective against enteroviral infections, salmonelloses (other than typhoid), and infections from *Shigella sonnei, Giardia lamblia, Enterobius vermicularis,* and enteropathogenic *Escherichia coli* (these last pathogens are still

Table 4-1. *Excreted Infections*

Biological group and organism	*Disease*[a]	*Reservoir*[b]
Viruses		
Coxsackievirus	Various	Man
Echovirus	Various	Man
Hepatitis A virus	Infectious hepatitis	Man
Poliovirus	Poliomyelitis	Man
Rotavirus	Gastroenteritis in children	?
Bacteria		
Campylobacter species	Diarrhea in children	Animals and man
Pathogenic *Escherichia coli*	Gastroenteritis	Man
Salmonella typhi	Typhoid fever	Man
S. paratyphi	Paratyphoid fever	Man
Other salmonellae	Food poisoning	Man and animals
Shigella species	Bacillary dysentery	Man
Vibrio cholerae	Cholera	Man
Other vibrios	Diarrhea	Man
Yersinia species	Yersiniosis	Animals and man
Protozoa		
Balantidium coli	Mild diarrhea	Man and animals
Entamoeba histolytica	Amebic dysentery and liver abscess	Man
Giardia lamblia	Diarrhea and malabsorption	Man
Helminths		
Ancylostoma duodenale	Hookworm infection	Man→soil→man
Ascaris lumbricoides	Ascariasis	Man→soil→man
Clonorchis sinensis	Clonorchiasis	Animal or man→snail→fish→man
Diphyllobothrium latum	Diphyllobothriasis	Animal or man→copepod→fish→man
Enterobius vermicularis	Enterobiasis	Man→man
Fasciola hepatica	Fascioliasis	Sheep→snail→aquatic vegetation→man
Fasciolopsis buski	Fasciolopsiasis	Pig or man→snail→aquatic vegetation→man
Gastrodiscoides hominis	Gastrodiscoidiasis	Pig→snail→aquatic vegetation→man
Heterophyes species	Heterophyiasis	Dog or cat→snail→fish→man
Hymenolepis species	Hymenolepiasis	Man or rodent→man
Metagonimus yokogawai	Metagonimiasis	Dog or cat→snail→fish→man
Necator americanus	Hookworm infection	Man→soil→man
Opisthorchis felineus	Opisthorchiasis	Animal→snail→fish→man
O. viverrini	Opisthorchiasis	Animal→snail→fish→man
Paragonimus westermani	Paragonimiasis	Animal or man→snail→crayfish→man
Schistosoma haematobium	Schistosomiasis	Animal or man→snail→man
S. mansoni	Schistosomiasis	Man→snail→man
S. japonicum	Schistosomiasis	Man→snail→man
Strongyloides stercoralis	Strongyloidiasis	Man or dog(?)→man
Taenia saginata	Taeniasis	Man→cow→man
T. solium	Taeniasis	Man→pig→man, or man→man
Trichuris trichiura	Trichuriasis	Man→soil→man

? Uncertain.
a. With all diseases listed, a symptomless human carrier state exists.
b. For helminths, the transmission process is given.
Source: Richard G. Feachem and others, *Sanitation and Disease: Health Aspects of Excreta and Wastewater Management*, World Bank Studies in Water Supply and Sanitation no. 3 (Baltimore: Johns Hopkins University Press, forthcoming).

commonly transmitted within affluent communities in industrialized countries).

The criteria chosen to separate categories I and II 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 tidy groups is the variable persistence of the pathogens involved. The extreme category-I pathogen that 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 and less on sanitation. A low infective dose, however, in an environmentally persistent organism 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. For them, induced immunity may be the best approach, as discussed above for

Table 4-2. *Environmental Classification of Excreted Infections*

Category and epidemiological feature	*Disease*	*Environmental transmission focus*	*Major control measure*
I. Nonlatent; low infective dose	Amebiasis Balantidiasis Enterobiasis Enteroviral infection[a] Giardiasis Hymenolepiasis Infectious hepatitis Rotaviral infection	Personal Domestic	Domestic water supply Health education Improved housing Provision of toilets
II. Nonlatent; medium or high infective dose; moderately persistent; able to multiply	*Campylobacter* infection Cholera Pathogenic *Escherichia coli* infection Salmonellosis Shigellosis Typhoid Yersiniosis	Personal Domestic Water Crops	Domestic water supply Health education Improved housing Provision of toilets Treatment of excreta before discharge or reuse
III. Latent and persistent; no intermediate host	Ascariasis Hookworm infection[b] Strongyloidiasis Trichuriasis	Yard Field Crops	Provision of toilets Treatment of excreta before land application
IV. Latent and persistent; cow or pig as intermediate host	Taeniasis	Yard Field Fodder	Provision of toilets Treatment of excreta before land application Cooking; meat inspection
V. Latent and persistent; aquatic intermediate host(s)	Clonorchiasis Diphyllobothriasis Fascioliasis Fasciolopsiasis Gastrodiscoidiasis Heterophyiasis Metagonimiasis Paragonimiasis Schistosomiasis	Water	Provision of toilets Treatment of excreta before discharge Control of animal reservoirs Cooking
VI. Excreta-related insect vectors	Bancroftian filariasis (transmitted by *Culex pipiens*) and all infections in I–V for which flies and cockroaches can be vectors[c]	Various fecally contaminated sites in which insects breed	Identification and elimination of suitable insect breeding sites

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

a. Includes polio-, echo-, and coxsackieviral infections: poliomyelitis; viral meningitis; diarrheal, respiratory, and other diseases (see Feachem and others, chapter 1).

b. *Ancylostoma duodenale* and *Necator americanus*.

c. *Culex pipiens* is a complex of mosquito species and subspecies. The principal tropical species, and the vector of filariasis in those tropical areas where the infection is transmitted by *Culex*, is *Culex quinquefasciatus* (previously also known as *Culex pipiens fatigans*, *C. p. quinquefasciatus*, or *C. fatigans*).

poliomyelitis. For category II, sanitation improvements reduce the efficacy of the longer cycles and thus have a greater overall benefit than for category I pathogens (for which 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 because 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 sites for their development, 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 of ova is so long, however, 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 (for example, storage of excreta for at least a year) is vital prior to reuse.

Category IV

This category contains only *Taenia saginata* and *T. solium,* the beef and pork tapeworms, respectively. Any system that prevents untreated excreta from being eaten by cattle and pigs 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 eating human feces deposited near the home or in the pigsty.

Therefore, the provision of toilets of any kind to which cattle and pigs 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 the tapeworm ova in their droppings on pastures. Personal and domestic cleanliness are irrelevant as long as toilets are used.

Category V

These are the water-based helminths, which need an aquatic host or hosts to complete their life cycles. Control is achieved by preventing untreated night soil or sewage from reaching water in which the 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 low contamination levels, and the requirements of adequate excreta disposal relative to 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 group, *Culex pipiens,* that 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 wherever 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 tracts, 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 skin lesions.

The implicit control measure is to prevent access of the insects to excreta, and 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. Cockroaches, flies, and *Culex* mosquitoes have numerous breeding places other than those connected with excreta disposal and, thus, can never be controlled by sanitation improvements alone.

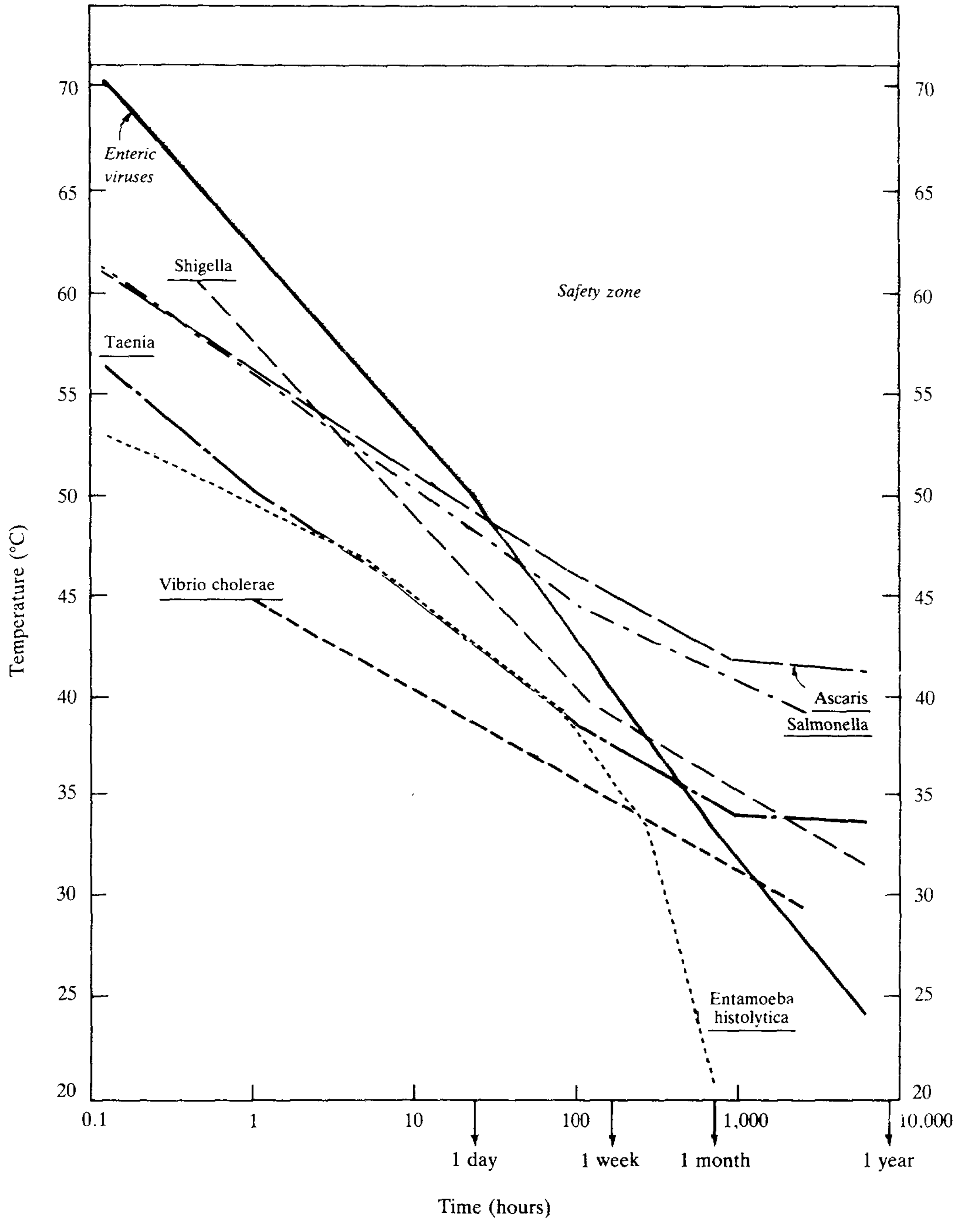
Health Effects of Treatment and Reclamation

As described above, some of the infections in categories II–V require for their control proper treatment before disposal or reclamation. Waste treatment technologies for developing countries depend upon the level of water service and the kind of sanitation system involved. The health aspects of three treatment options—stabilization ponds for waterborne wastes, night-soil digestion with or without methane (biogas) recovery, and composting—may be evaluated according to the time-temperature relations that achieve the death of excreta-related pathogens.

Minimal times and temperatures that will ensure pathogen death are shown in figure 4-1. The most resistant pathogens are enteric viruses and *Ascaris* eggs; by the time these are killed, all the others have died. The curve for *Ascaris* eggs is based upon a large body of data; that for the viruses is less certain. In any event, the typical temperatures reached during aerobic composting by the Beltsville Agricultural Research Center (BARC) process described in chapter 2 are more than enough to destroy all known pathogens.[4]

Figure 4-1 also indicates that anaerobic night-soil or sludge digestion—at the ambient or slightly raised

Figure 4-1. *Influence of Time and Temperature on Selected Pathogens in Night Soil and Sludge*



Note: The lines represent 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: Richard G. Feachem and others, *Sanitation and Disease: Health Aspects of Excreta and Wastewater Management*, World Bank Studies in Water Supply and Sanitation, no. 3 (Baltimore: Johns Hopkins University Press, forthcoming).

temperatures found in night-soil storage pits or vaults (say, up to 35 °C in tropical areas) for detention periods of twenty to thirty days—will substantially reduce but not eliminate *Ascaris* eggs in the sludge.[5] For digesters heated to 45 or 50 °C, complete destruction will occur. Storage in a well-drained pit for one year will also suffice for an essentially complete kill; the same is true for excreta in a pit privy or a composting latrine.

If pathogens are not removed by prior treatment, they can survive on soil as follows:

	Survival time
Viruses	$\leq$6 months, but generally $<$3 months
Bacteria	$\leq$ 3 years, but generally $<$2 months
Protozoa	$\leq$ 10 days, but generally $<$2 days
Helminths	$\leq$ 7 years, but generally $<$2 years

Survival of excreted pathogens on crop surfaces may be as follows:[6]

	Survival time
Viruses	MM$\leq$ 2 months, but generally $<$1 month
Bacteria	MM$\leq$6 months, but generally $<$1 month
Protozoa	M$\leq$5 days, but generally $<$2 days
Helminths	MM5 months, but generally $<$1 month

Stabilization ponds can provide adequate low-cost treatment for sewage. They are particularly effective in warm climates where a series of five to seven ponds, each with a retention time of five days, will remove all helminths and protozoa and reduce the concentrations of other enteric organisms to levels safe for irrigation.

Health hazards of night-soil and sewage-reclamation systems have been well documented.[7] The reclamation systems considered here include methane production at household and community levels, irrigation of gardens or crops, fertilization of fields or ponds for agriculture or aquaculture, and pig feeding. Areas of potential health hazard include exposure of the workers and contamination of foods.

Data on the health effects of night soil or sewage upon sanitation or agricultural workers are inconclusive, although the risk is self-evident. Although there is unquestionably a hazard, most surveys made to date reveal no greater susceptibility to disease than that of the general population in industrial countries.[8] An exception is a 1971 survey in India of workers on farms fertilized with raw sewage that reported significantly higher levels of intestinal parasites, anemia, skin disorders, and diseases of the respiratory and intestinal tracts.[9]

Risk to the general population is better known. Recent developments in China include night-soil treatment, along with snail eradication programs prior to use of night soil as fertilizer, to reduce prevalence of schistosomiasis and concurrently to reduce ascariasis.[10] Other reports of possible infection due to aerosols from spray irrigation in Israel, and to ridge and furrow irrigation of crops with poorly treated sewage in a number of places, reaffirm the need for careful selection and operation of waste treatment facilities that will adequately protect nonimmune human populations.[11] Where excreta are fed to fish or pigs—as in South and Southeast Asia, West Africa, and Central America—waste treatment should be complemented by careful cooking of the meat. Methane from a household biogas unit or a community digester has no hazard of infection, but the sludge or slurry will require the same treatment as that for night soil or sewage treatment plant sludge.

Risks of infection from eating foods grown with water or fertilizer from raw or treated sewage, sludge, feces, or urine depend upon the kind of crop and whether it is eaten raw, upon handling of the food before and after cooking, and upon the time-temperature factors in the interior of the food during cooking. No attempt is made here to generalize on effects of different methods of preparing and cooking contaminated foods. Eating raw or partially cooked pork or whole fish from animals fed on feces is clearly not safe. Nor is eating unsterilized watercress or other raw plants grown in contaminated water. If the meat, fish, or plant is cooked to the "well-done" stage, however, and no further contamination occurs during subsequent food handling, there will be no risk. The matter is a cultural and educational one whose influence on the design and operation of waste reclamation systems must be determined on a case-by-case basis.

Conclusion

Sanitation improvements are necessary but, in themselves, are not sufficient for the control of excreted infections. Nevertheless, without them, excreted infections can never be controlled. Other complementary inputs, such as improved water supplies and sustained health education programs, are essential for success. The theoretical, potential health benefits from environmental sanitation improvements alone and from personal hygiene improvements alone are summarized in table 4-3. The outstanding difference in the table 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 20—40 liters per capita daily of safe water are made available concurrently with sanitation improvements and if an effective and sustained program of health education is organized.

Table 4-3. *Potential Health Improvements*

Category of infection	*Potential improvements from* Sanitation alone	Personal hygiene alone	*Other control measures*
I	Negligible	Great	None
II	Slight–Moderate	Moderate	Proper waste treatment
III	Great	Negligible	Proper waste treatment
IV	Great	Negligible	Proper waste treatment
V	Moderate	Negligible	Proper waste treatment, animal control, or cooking of meat
VI	Slight–Moderate	Negligible	Insect control

If one considers the changes necessary to control categories III and IV, 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 that the literature on the effects of latrine programs often does not show a marked decrease in the incidence of infections in categories III through VI is because, although latrines were built, they were typically not kept clean and often were not used at all by children or by adults working in the fields.

This points to the importance of supplementing sanitation improvement projects with health education and training programs for users. Operational research is needed to develop effective ways of communicating simple hygiene habits and motivating users to adopt them. In addition, more information is needed on the destruction of pathogens in simple night-soil treatment systems, on viral survival in waste stabilization ponds, on the risks of groundwater pollution from on-site sanitation systems, on the health hazards of various methods of sullage disposal, and on methods of eliminating breeding of *Culex pipiens* in wet pit latrines.

Notes to Chapter 4

1. Much of this chapter is taken from the volume issuing from the Ross Institute's study. For a complete account of the Institute's work and its bibliographic base, see Richard G. Feachem and others, *Sanitation and Disease: Health Aspects of Excreta and Wastewater Management*, World Bank Studies in Water Supply and Sanitation, no. 3 (Baltimore: Johns Hopkins University Press, forthcoming).

2. For a more complete discussion of this topic, see chapter 5 in Richard G. Feachem and others, *Water, Wastes, and Health in Hot Climates* (Chichester: John Wiley and Sons, 1977).

3. Feachem and others, *Sanitation and Disease.*

4. Hillel I. Shuval, Charles G. Gunnerson, and DeAnne S. Julius, *Appropriate Technology for Water Supply and Sanitation*, vol. 10, *Night-soil Composting* (Washington, D.C.: The World Bank, 1980).

5. M. G. McGarry and J. Stainforth (eds.), *Compost, Fertilizer, and Biogas Production from Human and Farm Wastes in the People's Republic of China*, Publication no. IDRC-TS8e (Ottawa: International Development Research Centre, 1978).

6. Suggested criteria for reduction of the health risks associated with the agricultural reuse of excreta and sewage are presented in Feachem and others, *Sanitation and Disease*, and in standard works on irrigation.

7. Ibid.

8. Ibid. See also C. Scott Clark and others, "Disease Risks of Occupational Exposure to Sewage," *Journal of the Environmental Engineering Division, Proceedings of the American Society of Civil Engineers*, vol. 102, no. EE2 (1976), pp. 375–88; and W. Anders, "The Berlin Sewer Workers," *Zeitschrift für Hygiene*, vol. 1 (1954), pp. 341–71.

9. Central Public Health Engineering Research Institute, *Health Status of Sewage Farm Workers*, Technical Digest no. 17 (Nagpur, India, 1971).

10. McGarry and Stainforth, *Compost, Fertilizer, and Biogas;* and M. G. McGarry, "Developing Country Sanitation," Report to International Development Research Centre (Ottawa, February 1975).

11. Hillel I. Shuval, "The Uses of Wastewater for Irrigation, with Special Reference to Enteric Pathogenic Protozoans and Helminths," *Proceedings of the Conference on Sanitation in Developing Countries*, Oxford, England, July 1977.

5

Sociocultural Factors

NEARLY ALL STUDIES addressing the sanitation problems of the rural and urban poor in developing countries affirm the importance of social and cultural factors in the choice of appropriate technology. The operational recommendation generally made is to increase community motivation and participation in the planning and selection stages in hopes that community responsibility can be generated to use and sustain the system during the operating and maintenance stages. The widespread failure of community water supply and latrine programs, when measured by long-term successful operation or usage, points to the need for a more careful analysis of the sociocultural aspects of the choice of technology and for more specific operational guidelines.

This chapter summarizes the results of sociocultural surveys and case studies of social factors affecting the selection of sanitation technology that were carried out as part of the World Bank research project that preceded this volume.[1] These detailed case studies were limited to Latin America; thus, their results must be interpreted with caution by those working in other parts of the world. Many of the Latin American findings were supported by surveys conducted in Asian and African communities, but constraints of time prevented verification of these surveys through additional case studies.

The questionnaire used in all communities was designed to provide community input during the design stage of project implementation; it generally followed the form used by White, Bradley, and White in East Africa.[2] Such a questionnaire is one of the behavioral scientist's tools for carrying out stage 1 in figure 1-1. Its purpose was to find out what community members thought about their present methods of water supply and excreta disposal and how they would respond to an opportunity to change those methods.

The survey first attempted to determine how people perceived their environment. Did they think of it as a healthy place to live? What were their criteria for evaluating a good or healthy environment? Did they see a relation between environmental sanitation and good health? Did they view environmental sanitation as a problem at all? If they did, why was it a problem and how important was it in relation to other perceived problems?

Second, the survey investigated existing practices related to water use and excreta disposal and preferences for improvements. What were the problems associated with obtaining water? What level of service would be desirable and what was acceptable? What constraints were perceived in obtaining the desired improvements?

The survey also sought to identify incentives for change. Were the people aware of alternative sources of water supply and methods of excreta disposal? What were the perceived costs and benefits of the alternatives? Would community members be willing to collaborate with neighbors or contribute money, time, or effort to improve their existing water supply and sanitation facilities?

To supplement the survey, the researchers used various anthropological techniques in the Latin American field studies, including direct observation of water-carrying tasks and water reuse practices, indirect observation of personal hygiene and habits of latrine use, interviews with local leaders and individuals involved in sanitation programs, and informal conversations with local storeowners and craftsmen. One of the methodological conclusions from the case studies was that, without these "unstructured" information-gathering techniques to supplement the formal surveys, the responses obtained in the latter were often misleading or so incomplete as to be useless for guiding project design.

In addition to community-based data collection, pertinent information was assembled on the national and regional organizations involved in community water supply and waste disposal improvement. Both the successful and unsuccessful components of present and past programs were examined. This information on institutional issues has been incorporated in the program recommendations presented in chapter 7 of this appraisal.

Survey Results

Although each of the case studies provided many useful and original insights, the generalizations presented below represent the central and pervasive findings on environmental sanitation. These findings can also provide planners with some indication of the kind and quality of information that can be collected through a survey given before a project's initiation.

Perceptions

If the majority of a population perceives their environment to be healthy, it is for reasons unrelated to sanitation. Many people believe their environment is healthy because it provides fresh and good air, good climate, or accessibility (for example, is "close to the highway in case anything goes wrong"). In crowded, concentrated settlements, a healthy environment is viewed as one that allows for privacy and is characterized by good relations with one's neighbors. Significantly, all of the reasons cited above are based on respondents' observations of their immediate surroundings. A healthy environment is certainly not associated, in residents' perceptions, with abstract theories on disease vectors or with contamination through contact with nonvisible pathogens in water or wastes.

In contrast, those who perceive their environment as unhealthy most frequently cite reasons related to poor sanitation. Individuals in this category are a small minority in rural communities and a significant majority only in some urban fringe communities. Again, visible contaminants—such as dead animals in the water source—are often included in explanations of why a water source was "bad." Most believe water quality is good if the water looks clean. Color, taste, and smell are important criteria. Where improved supplies exist, the water may be considered of good quality because it is piped or introduced by a government health institution.

An understanding of the relation between water and health may occur when consumers are suddenly deprived of their utilities after an extended period of use. When their piped water system broke down and they were forced to use an unprotected well once again, the women of one Mexican village observed an increase in diarrhea among themselves and their children, and they attributed this to the change in water source.

Preferences and practices

Abundance and proximity are the two primary qualities appreciated in a water supply. Two of the most objectionable factors associated with an improved water supply are cost (if the water is paid for) and the crowding, quarrels, and problems with neighbors that often accompany many households' sharing the same public tap. In many cases, the opportunity for socializing while drawing water or washing clothes is not considered a benefit and may even have a negative value.

In communities where public taps have been introduced, most households desire greater accessibility through the installation of more taps at shorter distances or through the provision of private connections. Where public taps are close and a private connection involves additional cost, many prefer, as a cheaper alternative, the use of a hose to fill large drums placed next to the house.

An aesthetically attractive facility for excreta disposal, with a shiny porcelain seat or a brightly painted cement floor, is preferred over cheaper, less attractive alternatives. Although people use a squatting position when defecating in the fields in Latin America, they prefer a latrine with a seat.

Where lack of space or rocky soil are constraints for the installation of household latrines, there is an expressed and sometimes observed willingness to use a public facility or to share one with neighbors. People usually share latrines only with close friends, relatives, or good neighbors. Where sanitary facilities are maintained by attendants, however, the demand for use of public facilities is high.

Once a latrine is filled, many households continue to use the superstructure by transferring it to a new site. Most people, however, perceive a need for technical assistance when initially installing latrines, and without continuous or at least periodic promotion—even in communities where initial acceptance is high—new families do not usually take the initiative to install a latrine.

Incentives

People can be successfully motivated to install excreta disposal facilities by: a desire to acquire the benefits of another service, such as a health clinic or an improved water supply; population pressures causing crowding and an increased need for privacy; interest in acquiring "modern" conveniences in the village or what are regarded as status symbols (either by definition of the village leaders or by the awareness of models from more developed countries created by the tourist industry); and social pressures to comply with a collective village decision arrived at through a consensus of leaders and household heads.

In almost all of the communities studied, the people offer some suggestions for improving the existing water supplies or sanitation facilities (or both). Though lack of economic resources is often given as a reason for not having implemented ideas for improvement, lack of leadership and lack of technical knowledge are cited almost as frequently in some communities and more often in others. People are more willing to give time in working to improve their sanitation facilities than to pay more than a very small amount of cash for improvements. Those unwilling to collaborate with others to improve water supplies are a small minority and cite as their reasons previous bad experiences, poverty, or that the present supply is good or close enough for their needs.

Motivation

The need for different or improved excreta disposal facilities is rarely given priority except when the community has become crowded, housing is concentrated, and the lack of privacy has become a problem. As a result of being linked with a need perceived to be of higher priority—such as health services, water supply improvements, or income-generating projects introduced through integrated community development programs—the installation of latrines or other means of excreta disposal can receive substantial community support and acceptance. In marginal squatter communities, a major constraint to investing in improved sanitation is the fear of eviction.

Community values of unity and progress may be considered more important benefits than cleanliness and sanitation in communally approved projects for the installation of excreta disposal facilities. The costs (in money and time) of installing a latrine may be perceived as minor when compared with the costs (in social pressure, loss of good will, and deterioration of solidarity) of not installing one.

The extent of community involvement in environmental sanitation projects is directly related to opportunities for frequent contact and the exchange of information with technically informed individuals. When the facilitators or promoters presenting a project are socially and culturally similar to the population with whom they are working, communication is more effective.

A general philosophy that nothing should be wasted was evident in most of the communities studied, particularly in the rural ones. Water from laundry is stored for later use to settle dust and clean floors. Water used to wash dishes, soak corn, or clean vegetables is saved and fed to chickens, pigs, and other small domestic animals along with food crops. Reuse of human excreta is an understood concept and is practiced traditionally in Latin America, albeit in a less advanced and systematic way than in Asia. Reuse is informal—often not spoken about because of the sociocultural taboo surrounding the subject—and it takes place primarily in individual households. Defecation in cornfields or on coffee plants is considered to serve a fertilizing function. Similarly, fruit trees are purposely planted over old, filled latrine pits. In some areas, human excreta deposited near the house are consumed by pigs. This last practice is sometimes formalized, when penned pigs are released periodically to clean areas that have been designated and used for the depositing of human waste. Native pigs are sometimes even preferred over new breeds because they carry out this important function and can be fed corn and scraps instead of commercial concentrates. Behavioral patterns incorporating excreta reuse as a principle can provide the basis for uneducated people to understand composting and biogas when these new technologies are adequately explained.

When there exists a credibility gap between external agencies and communities because of past community experiences with abortive attempts to introduce innovations or compulsory programs, people are less willing to collaborate until materials or technical assistance are actually seen or made available. When communities are legally authorized to keep the fund for water supply maintenance in the community, or when economic resources for sanitation are made available through income-generating projects, local people take the initiative in defining as well as solving their own problems, and popular participation is more pervasive.

Behavioral Science and Sanitation Project Design

These highly specific findings from structured surveys are only a start in providing planners with an understanding of the social factors that influence the thinking that will determine whether potential users will accept, properly use, and maintain the services provided. A limitation of the use of questionnaires is the high cost in time and trained personnel needed to analyze a survey administered in every community to be served. The objective of incorporating the techniques of social science should not be to provide a few with custom-made latrines, but to provide many with acceptable sanitary facilities they are willing to use and maintain.

Another problem with surveys is the difficulty of obtaining reliable data on which to base decisions. When asked if they would be willing to contribute to projects, people must know how much, and of what, they are being asked to contribute. People are reluctant to respond when given a choice expressed in a hypothetical manner. Yet, when the technology suggested for a community is new to them, it is hard to pose concrete questions that will be meaningful.

A survey preceding a proposed project also risks unintentionally misleading respondents into believing that an effort is being made to solve their particular and immediate sanitation problems. Raising false expectations has contributed greatly to the credibility gap that exists between communities and outsiders. People's past experiences with unfulfilled promises have created in them an unwillingness to become involved in self-help projects unless they can actually see materials or a similar demonstration of commitment on the part of agencies offering them assistance.

The limitations of surveys in predicting users' preferences and willingness to pay have important implications for planning. The case studies suggested that surveys are most productive when complemented with unstructured information-gathering techniques at particular points in project design.

There are three components of project design that can be greatly strengthened by well-timed and -planned inputs from the social sciences: selection of technology, its diffusion, and its adoption. These major components, and the kind of input from social science recommended for each, are summarized in figure 5-1. The discussion below elaborates on the integration of the inputs into these components of project design.

Selection of technology

Insights into the reactions of users must be found in the study of communities in which technologies have already been introduced and accepted (or rejected). The communities should be as culturally and environmentally similar as possible to those in the area or region selected for sanitation improvement. Through a preliminary analysis of agency records, researchers can find out how much consumers have promised to contribute and how much they are actually contributing to maintenance of sanitation systems. The research will indicate the willingness of future beneficiaries to support such maintenance through contributions of money or time.

On the basis of this preliminary research, technical and administrative packages can be developed for communities environmentally and culturally similar to those studied. In this way, when the range of alternative technology is made available to consumers in the selected area, promoters can be as specific as possible about contributions and responsibilities expected of the community.

Means for the diffusion of technology

Because of the low priority given to sanitation needs in many communities, planning at the national level

Figure 5-1. *The Sociocultural Dimension of Sanitation Project Design: Contributions of Social Science*

Design of technology: research of selected area

The innovation:
- is technically feasible
- is cost efficient
- can be understood by users
- fulfills users' needs and expectations
- is affordable
- can be maintained by users

Means for the diffusion of technology: evaluation of existing institutions and programs

Channels and systems exist for:
- responsive administration
- promotion of activities and health education
- efficient delivery of service
- instruction on operation
- training in maintenance
- effective delegation of authority
- periodic monitoring

Motivation for the adoption of technology: consultation and community organization

The communities have input to:
- project initiation
- design (choice of level of service, location, and the like)
- scheduling labor-intensive activities
- instruction on operation
- training in maintenance
- fee collection (frequency of and mechanism for)
- authority to enforce sanctions (for tardy fee payments, noncompliance in maintenance, and the like)

should link the disposal of human waste with other services given higher priority by the communities (for example, water supply or health clinics). In the rural areas, community involvement in planning water supply and sanitation projects usually requires the creation of a branch office of the responsible agency that will be accessible to consumers and that has decisionmaking power for project selection and development in line with the policies and priorities established by the agency's central office (see chapter 7).

For purposes of liaison with the community, the agency responsible for water supply and sanitation should rely on facilitators or promoters assigned to an existing local agency such as a health clinic. If this kind of personnel does not exist, teachers or agricultural extension workers should be requested to assist in technical tasks, community organization, and health education activities. The facilitators should be natives of the region, they should have had experience working in the area, and they should share the cultural perspectives of the people with whom they will be working. An effort should be made to recruit women as well as men so that information on improved hygiene practices related to water supply and sanitation can be more effectively communicated to local women and their children. The facilitators should receive intensive training in the technical aspects of the technology and its promotion, and they should be provided with adequate transportation and visual aid materials if they are responsible for promoting the technology in a number of communities.

When an appropriate organizational structure does not already exist at the community level, project participants should be expected to organize a locally selected committee or cooperative to coordinate and oversee the community's contributions to the project. The case studies suggest that such committees are capable of assuming a wide range of responsibilities when provided proper authority and guidance. These responsibilities can include providing liaison between the agency and the community, organizing and maintaining records of the voluntary labor force, selecting community members to be trained in facility maintenance, collecting the maintenance fee, keeping accounting ledgers, and filing periodic reports to the responsible authority concerning the results of these activities.

When the promotion of a project at the community level is the responsibility of an individual or institution involved in other activities, initial participation may be high. Continued promotion, however, often is not given because energies must be dedicated to competing activities that may also have the incentive of producing an income (for example, selling medicines, giving injections, and other related health activities). For this reason, promotion should continue on a periodic (campaigns by promoters) or continuous (campaigns by radio) basis long after projects are initially constructed.

Motivation for the adoption of technology

Because urban and concentrated rural settlements consider sanitation more of a problem than do dispersed communities, initial efforts to introduce sanitation technologies are likely to be more effective in urban than in rural areas. The existence of conflicting factions and the fear of eviction (in squatter communities) may, however, mean that monetary or labor contributions will be more difficult to obtain. In the rural areas, sanitation can sometimes be linked with a request for an improved water supply, which is more often the community's priority. If the projects are implemented simultaneously, they will be viewed as related, and the need for maintaining both will be clearer.

When the technology is understood by the population, there is no need to build demonstration models to promote it. If it is not understood, the use of slides or other visual media and visits to prototypes may be a more rapid means of gaining the support of community leaders than the building of demonstration models in each community. When adequate examples are not available, however, demonstration models will usually be necessary. With any project, once the agency and the community have come to an agreement to undertake the project, expected contributions and responsibilities should be formally committed before its initiation.

For the most efficient planning, communities should have some input into scheduling installation and construction activities according to seasonal migration patterns, planting and harvesting seasons, and climatic cycles. Decisions about the location of water distribution outlets, colors for the sanitation facilities (if latrines are to be painted), when maintenance fees should be collected (monthly, bimonthly, or by some other schedule), and options for levels of service should be allocated to consumers so that community initiative in decisions affecting the care and maintenance of the facilities will be encouraged. Community leaders and project participants should also be encouraged to establish criteria by which individuals not participating in the original project may later be included.

To ensure adequate maintenance of facilities, local residents should be trained in simple procedures and in the reporting of major malfunctions to responsible authorities. Fees are more likely to be collected if they are maintained by an appropriately authorized community organization, such as a "Water Supply Improvement Committee." The local group should be required to maintain records and file periodic reports on its collections and expenditures, and it should have authority to impose sanctions against those who fail in their committed payments.

A system for periodic project monitoring should be established. A monthly visit by the local sanitary inspector or some other authority from the responsible agency can be an effective motivational tool when it is carried out in a culturally sensitive manner. Any problems that have arisen with use of the facilities can be discussed with local leaders in a nonthreatening manner, and joint solutions can be negotiated. The visits will not only motivate communities to care for the facilities, but they will also provide agencies with client contact and important feedback on changes in water use and sanitation practices that have occurred after the introduction of new technologies.

Conclusion

Many of these sociocultural aspects of the case studies' findings seem self-evident. It was very difficult, however, to find examples in the field of the widespread diffusion of new technologies or of the sustained, successful operation of community water supply and sanitation facilities. In some cases failures were from poor technical design or the lack of institutional support. But, in many cases, the major problem was that the social and cultural factors discussed above had been ignored by planners. These "software" components of appropriate sanitation technology are crucial to its successful introduction and diffusion.

Unfortunately, research into the design and delivery of these project components is scarce, and what is available tends to be extremely site specific. Perhaps this is a reflection of the nature of the inputs themselves. Because these sociocultural components constitute the link between a technology and a particular community, it is obvious that they must be adapted to suit the local context. Yet, at the least, an analysis of which techniques of social science and which delivery methods have and have not been successful in the implementation of sanitation projects needs to be attempted on a wider scale. If such an effort fails to reveal any common characteristics of successful or unsuccessful strategies, then a cumbersome and expensive site-by-site approach, such as that used in this study, may have to be adopted.

Notes to Chapter 5

1. For a more complete analysis of the sociocultural case study results, see Mary Elmendorf and Patricia K. Buckles, *Appropriate Technology for Water Supply and Sanitation,* vol. 5, *Sociocultural Aspects of Water Supply and Excreta Disposal* (Washington, D.C.: The World Bank, 1980). Much of this chapter is taken from that work.

2. G. E. White, D. J. Bradley, and A. U. White, *Drawers of Water: Domestic Water Use in East Africa* (Chicago: University of Chicago Press, 1972).

Part Two

Program Planning and Development

6

Implementation of Appropriate Sanitation Technology

IN DESIGNING A PROGRAM for the implementation of appropriate sanitation technology, an important question to answer is: why have inappropriate technologies been chosen in the past? This is really several questions in one. Are alternatives to those technologies chosen available? If so, what is the appropriate procedure for selecting among the alternatives? Given that selection process, why has the result in the past been different from the one expected from what now appear to be more appropriate choices? Finally, how can those factors responsible for the difference be altered or overcome to ensure that appropriate choices are made in the future? This chapter attempts to answer such questions as they relate to sanitation alternatives.

Obstacles

There are many points on the course toward implementing an appropriate sanitation technology where the planner can encounter an obstacle and be sidetracked. The first and most obvious problem found in the case studies, which form the basis of this analysis, is the information gap. As described in chapter 2, many nonconventional sanitation technologies are being utilized around the world, but there is a real dearth of detailed information on them. At the outset of this study, the World Bank contracted the International Development Research Centre (Ottawa, Canada) to carry out a detailed bibliographic search for information on sanitation technologies. They undertook their investigation along two lines: through a rationalized computer search of a number of North American data bases and through an ad hoc, manual search of selected private and institutional libraries. The "key word" computer search produced about 18,000 titles, which were manually screened to obtain a short list of about 700 articles that potentially included technical information useful to developing countries. These articles were acquired and read, and 188 of them were chosen for inclusion in the annotated bibliography. Thus, only about 1 percent of the published literature on wastewater was found to relate to nonconventional sanitation technologies. The manual search yielded much better results because it was directed toward those individuals and institutions known to have an interest in the subject. The final bibliography contained summaries of 528 articles, of which nearly half were previously unpublished.[1] Efforts such as this can help bridge the information gap directly.

With few engineers aware of the range of sanitation technology available, it is not surprising that even fewer planners and administrators know about the present variety of technological alternatives. This lack of knowledge has often meant that requests for sanitation studies have called only for the examination of different configurations of sewerage systems. The least-cost evaluation has usually been limited to pipe sizes and different treatment alternatives. Once a least-cost sewerage system has been designed, its financial implications have been derived and compared with the city's capacity to raise funds. In most cases, this comparison has led to a recommended staging of sewer construction to serve downtown and wealthier residential areas (often the only ones with piped water) in early years and to no recommended improvements for those living in the rest of the city.

Even if terms of reference have included the evaluation of nonconventional options, there have been biases in the process of technology selection that have favored sewerage systems. The background and training of the bulk of consulting sanitary engineers certainly has constituted one bias. With very few exceptions, this orientation is heavily directed toward sewerage modeled on systems in developed countries. Thus, most sanitary engineers generally are good at designing a workable sewerage system as one alternative, but they rarely have the knowledge or experience to "preselect" the best, and likely more appropriate, alternative technology to compare with sewerage. If problems are encountered in designing a sewerage system to fit the site, they can usually devise ways to overcome them. But if problems arise in the design of an alternative technology, it is often abandoned, rather than adapted, because of the engineers' lack of design experience. Only time and increased exposure to nonconventional solutions can overcome this difficulty.

Concurrently with the design of alternatives, the feasibility team prepares estimates of the demand for the service to be provided. This is another area in which existing practice has favored sewerage. If economics is "the dismal science" (as Thomas Carlyle called it in 1849), engineering is the optimistic one. Linear demand projections made from tiny bases persist despite historical evidence that, over the long run, demand growth is S-shaped and asymptotic. The supplies of complementary inputs, such as piped water and additional housing, have been assumed to be perfectly elastic. The influence of price on consumption has been ignored. The intricacies of urban growth patterns have rarely been explored, although they often are based upon an influx of population much poorer and less able to afford service amenities than present populations. Thus, when historical rates of growth in demand have been projected into the future, the lower consumption patterns of the new migrants are grossly overestimated. Because sewerage master plans often cover periods of more than twenty years, these errors have been compounded over time until a highly unrealistic picture of demand is created and used as the frame for testing alternative technologies. The reason that the assumption of rapid growth in demand has favored sewerage over most nonconventional systems is that those technologies with large economies of scale are more economical under conditions of rapid growth. As pointed out in chapter 3, however, the financial consequences of investing in such large-scale technologies can be very serious should demand turn out to be lower than projected.

There is one aspect of demand projection that deserves special emphasis because it has been ignored for so long. This is the social, or micro-level, basis of any demand analysis. Behind any set of such numbers are the consumers whose individual needs and resources form the boundaries of consumption patterns. When working in a familiar and homogeneous social environment, such as a Western European country, an engineer incorporates social factors into the demand analysis almost automatically because the engineer himself, generally, is a part of that same social fabric. But, in developing countries, it is necessary for the engineer to make a real effort to discover the users' practices and preferences in order to satisfy them at the least cost. Habits and ideas regarding human waste disposal are highly variable across cultures and are not easily discerned by the casual visitor. There are many examples in which cultural misunderstandings have led to nonuse or misuse of new sanitation technologies. Factors such as the color or location of a latrine may have little technical import and yet be crucial to the acceptance and use of a facility. In one new African community, an engineer designed the bathrooms to be in the front of the houses so that the connection to the sewer would be as short as possible. The engineer did not know, however, that people who were to use the facilities were unwilling to change their traditional practice of having the latrine in the back of the house, away from the view of passersby. Had this seemingly simple consultation with users been made and their preferences determined before the sewers were laid, the bathrooms could have been placed between the adjoining backyards of the houses at little additional cost. In this case, because the users had not been consulted during the design process, by the time they discovered the plans and complained about them the sewers were already in place. Because the bathrooms then had to be moved to the backs of the houses, the system that was eventually built was far from the least-cost design.

Even when demand analysis has been properly done and consumers' preferences and financial constraints are known, it is possible to choose the wrong technology by applying an inappropriate selection test. The most common fault has been the use of financial rather than economic costs in the least-cost analysis. The reasons why sewerage benefits from financial rather than economic costing are that it is relatively capital intensive (and financial interest rates are generally below the opportunity cost of capital); it is relatively import intensive (and foreign exchange is often officially undervalued); its cost to the householder in needed plumbing and internal facilities is very high; it has relatively high water requirements (which are usually omitted from the cost comparison or included at a market price below long-run production cost); and it possesses larger economies of scale than most nonconventional systems for waste disposal that are not properly valued where design populations are used for costing.

Incentives

Given the diversity of the obstacles to the selection of appropriate sanitation alternatives, a variety of incentives or policy changes is likely needed if the conventional practices of engineers and their clients in developing countries are to be revised. Some of these changes are obvious from the description of the problems. For example, it is necessary to ensure that terms of reference for sanitation master plans include the examination of alternatives to sewerage. The international lending agencies can have an important influence here because they are often called upon to review terms of reference for studies of projects they will be asked to finance. The information gap can be closed by the widespread dissemination of information such as that collected during this study. There are two areas, however, where concerted efforts will have to be made to permit a more equitable consideration of nonconventional solutions for sanitation.

The first is a revision of the methods that have been used by consulting engineers and planners in selecting among technologies. The socioeconomic base for feasibility planning must be improved. This probably means that multidisciplinary teams—including an economist/planner and behavioral scientist as well as an engineer and financial analyst—should be used in the first phase of planning and demand analysis. The amount of direct interaction with, and information gathering within, the community to be served should be increased to provide better data for estimating future demands for different kinds of sanitation service. The demand analysis should be disaggregated according to income, social status, housing, or other groupings that are likely to affect demand. In some cases, it will be appropriate to look for the critical constraints to demand growth. For example, the growth of the water supply system, and the rapidity with which new connections can be made, may be a constraint to the growth of a sewerage system that to function properly requires house connections for water. Similarly, if the local housing market is tight and the city is densifying rather than spreading as population increases, the demand for new facilities (rather than the intensified use of original facilities) is likely to be constrained. Income generally imposes another constraint on the demand for sanitation services. Especially in areas where the behavioral scientist finds that improved sanitation is not a high priority of the inhabitants, the willingness of potential users to pay for any new system is probably low.[2] In poor areas, unless the residents have secure tenure on their property, they may be unwilling to pay anything for sanitation improvements they cannot take along with them if they are forced to move. If the estimation of demand does not take into account factors such as these, it cannot provide a sound basis for the selection of technology.

The contribution of the economist and behavioral scientist to the feasibility study should not stop with the demand analysis. The economist's involvement in the preparation of appropriate least-cost estimates for the various feasible alternatives has been discussed in chapter 3. The behavioral scientist's work in eliminating socially infeasible possibilities—and in acting as liaison between the community and the design engineer in preparing the final project designs—is covered in chapter 5. In addition, the behavioral scientist must plan the method by which the community makes its choice among the final alternatives and associated costs. Both economist and behavioral scientist should be involved in the monitoring and evaluating phase of project development.

The second area in which new incentives will be required for the promotion and adoption of appropriate sanitation technologies is that of financing. In many developed countries the central government provides large subsidies or grants for the construction of interceptors and sewage treatment plants.[3] This obviously makes it very difficult for a community to choose any other waste disposal system, since it would have to bear the alternative system's full financial cost.

An additional financial disincentive in some cases has been the use of consultant fee schedules that have been tied to a percentage of the construction costs of the project the consultants design. Because it often takes more time and ingenuity to make a low-cost sanitation technology such as vacuum cartage function at optimal efficiency than it does to use tried and tested rules for sewerage design, it would be unfair to expect consultants to design effective alternative systems for less money. Yet this would be the result if their fees continue to be based on project costs.

International and bilateral lending agencies have also exerted a financial bias toward sewerage systems in the past. Many made loans only to cover the foreign exchange cost of projects. This meant that those technologies that were relatively intensive in imported equipment (and consultants) generated interest and support from the agencies, whereas those that used mostly local materials, and perhaps even self-help construction, had too small a foreign exchange cost for the agencies to be interested. Fortunately, most aid organizations, including the World Bank, have now changed their policies to permit financing of projects' local cost components. There has also been increased interest in financing projects whose benefits are directed to the poorer groups in society. These two changes should promote the continuing, increased interest of aid organizations in low-cost sanitation packages.

Along with such changes in the financial policies of aid organizations will have to come changes in the kinds of institutional structures these agencies work through. Where household systems such as improved pit latrines are the appropriate technology, much of the construction work can probably be undertaken by the individual households with supervision and technical assistance from a local organization. The best local organization to provide this assistance may well be the health clinic or agricultural cooperative, which may already have local personnel and knowledge of the community, rather than the centralized water or sewerage authority. Channeling funds through an organization whose primary function is different from the activity being funded will certainly present unusual challenges in promoting traditional cost recovery and management objectives while retaining the independence of the organization to pursue its primary responsibilities.

As is emphasized elsewhere in this study, the preparation of low-cost sanitation projects is likely to require more time and local involvement than has been devoted in the past to sewerage projects. Weak or nonexistent local institutions will present a more serious constraint to project preparation, since much of the selection process depends on local understanding of the beneficiaries' needs and preferences. It is difficult to substitute foreign consultants for this, although it may be possible to use local university or municipal personnel.

In sum, the obstacles that have created a bias in favor of sewerage in the past are gradually being overcome. Much of the necessary technical research into appropriate technologies for sanitation has been accomplished, and a widespread effort of dissemination must now be made to close the information gap. Terms of reference for sewerage projects are beginning to include the development of alternative sanitation components. The importance of economic and social analysis to supplement technical and financial evaluations is now widely accepted and is beginning to find its way into feasibility studies. In addition, changes in the policies and objectives of international and bilateral lending agencies have created incentives to promote the selection of more appropriate technologies.

The success record of individual government policies that could encourage better sanitation programs is mixed, with much room for innovation. Governments in developing countries need to consider carefully what they hope to achieve through subsidizing costs for waste disposal. If the objective is improved community health, then they should make funds available for packages designed to achieve this goal at the least cost. These might include immunizational and educational components along with low-cost methods of waste disposal. Even the most sophisticated sanitation technology will not bring health improvements unless properly used and combined with good users' habits of personal hygiene. If a government's objective is the long-term protection of the environment, then it should subsidize those technologies that promote this goal through dispersed recycling of treated waste. In general, sewerage systems are not the least-cost way of achieving either better health or environmental protection. To subsidize them exclusively may preempt the appropriate solution.

Overall, the climate for a major breakthrough in providing sanitation services to the large majority of people in developing countries who currently lack them is probably better now than it has been in the past thirty years. A continued effort to improve incentives and remove constraints to the choice of appropriate sanitation technologies can provide the needed groundwork for such extended, global efforts as the International Drinking Water Supply and Sanitation Decade of the 1980s.

Notes to Chapter 6

1. See Witold Rybczynski, Chongrak Polprasert, and Michael McGarry, *Low-Cost Technology Options for Sanitation: A State-of-the-Art Review and Annotated Bibliography* [a joint effort by the International Development Research Centre and the World Bank: IDRC-102e/*Appropriate Technology for Water Supply and Sanitation*, vol. 4] (Ottawa: IDRC, 1978).

2. Willingness to pay, of course, is a broader concept than ability to pay, and this applies to high-income areas as well as low-income ones. If households already have well-functioning (and probably expensive) septic tanks to dispose of household wastes, householders are unlikely to be willing to discontinue use of septic tanks for connection to a sewerage system even if they can afford to do so.

3. In the United States, for example, the government finances 75 percent of total construction costs, and states (such as California) provide another 12 percent.

END

7

Institutional Requirements

FOR THEIR SUCCESSFUL DEVELOPMENT and implementation, water supply and sanitation projects require an institutional framework that allocates authority and responsibility for each phase of a project. Policies, organizational management, and financial resources must be legally established to ensure continuity of efforts in the sector. The institutional and policy requirements for a successful water supply and waste disposal program will be examined in the following section; in brief, they are as follows:

- A sector strategy supported by government
- Frequent reassessment of technologies
- A stable, autonomous institution with clear responsibilities
- Manpower development programs and career opportunities in the sector (not only for technical, financial, and managerial staff but also for behavioral scientists and health and community workers)
- A tariff policy that ensures financial viability and encourages efficiency and equity.

Essential Components

Domestic water supply and excreta disposal are part of the larger water supply and waste disposal sector, which itself may be part of a much larger sector such as water resources. In any case, specific sectoral policies and organizational arrangements should cover domestic water supply and excreta disposal. In addition, actions and policies of the health and education sectors can have significant effects on water supply and sanitation. The health ministry, for example, is frequently responsible for rural water supply and sanitation.

Sanitation projects often fail to achieve the objectives they are designed to meet because the sector itself is neglected, disorganized, or does not receive the necessary support from government. Neglect is usually greatest in rural areas, villages, small towns, urban fringe areas, and slums. One reason for such neglect is the high visibility of projects for major urban areas and the ability of the middle-class, urban consumer to preempt both government attention and funds. Factors contributing to disorganization are the lack of a comprehensive policy for the sector, a lack of understanding of the benefits the sector provides (because they cannot be easily quantified), and a lack of knowledge about the low-cost technologies appropriate for service levels affordable by the urban and rural poor.

Government support on a steady, long-term basis is essential to avoid the destructive stop-and-go of program preparation and implementation. Neither agencies nor communities nor users will make commitments and undertake construction if clear evidence of consistent government support is not forthcoming. The sudden withdrawal of support—or failure to follow through once a project has been prepared—may permanently discourage a community from undertaking a scheduled project or supporting future ones.

The reassessment of technology at frequent intervals is necessary because of a natural tendency of designers to base their selection on past, successful experiences without necessarily considering present local conditions in sufficient detail. This tendency is particularly relevant to the transfer of technologies from industrialized to developing countries, where the requisite trained manpower and access to equipment, spare parts, or repair facilities frequently are not available. Furthermore, the particular sociocultural environment can preclude the acceptance of some technologies if major educational efforts are not directed toward the intended beneficiary, and indigenous religious beliefs can prevent the use of others. Periodic monitoring of past projects, when coupled with analysis of specific, current conditions, can enable an institution to learn from its own experience.

Stable, autonomous institutions offer career opportunities that attract competent staff and can establish financial and tariff policies that can enable the institution to undertake long-term development programs without interruptions and excessive political interference. The two most important ingredients for the success of a water and sanitation agency are competent employees and sufficient funds. A staff subject to dismissal with each political change loses motivation and effectiveness. Funds that can be easily diverted to other sectors to satisfy needs of other constituencies delay implementation of sanitation projects and, when they are required as matching funds for borrowings, may postpone projects indefinitely. Institutions should, therefore, be granted at least the degree of autonomy that enables them to attract and keep effective staff and to set financial policies allowing the viability of their undertakings.

In addition to simply attracting competent staff, an organization should offer salary increases and related benefits to minimize staff turnover, including the provision of training programs to increase staff capacities. Because public institutions are often unable to offer staff compensation equal to that prevailing in the private sector, trained staff often leave public service after relatively short periods of employment. Such training still provides an overall economic benefit to the country, but it follows for the public institution that training programs must be continuous to ensure the availability of qualified candidates and to minimize institutional disruption. In addition, such career opportunities should be clearly identified through a program for staff development and promotion.

Tariffs for services rendered not only provide for the financial viability of the executing agency but enable it to cross-subsidize a minimal standard of service at prices affordable to the poor and to encourage efficiency by charging the real cost of facilities to those who can afford it. Appropriate tariff policies will reduce the need for government subsidies and thereby make the sector less dependent on scarce government funds.[1]

A sound tariff policy developed and supported at the national level is usually necessary to ensure that needed increases in tariffs will not be delayed by local political pressures. In addition, departments responsible for planning or financing can develop guidelines to aid communities in determining the economic cost of the services received for purposes of tariff setting and in designing tariff structures to provide cross-subsidies for poorer consumers. As is true of technology selection, the basic tariff policy should be set at the national level, and the application of the policy in a particular community should be left to the community organization.

Policy Implementation

For water supply and excreta disposal projects incorporating other than conventional technologies, further institutional and policy strategies should provide for:

- Government commitment to the program evidenced by clear objectives, policies, and reliable allocation of adequate staff and funds
- Community participation in evaluation and selection of standards for service levels and appropriate technology
- Community participation in the construction and selection of operating and maintenance arrangements in communities too small for an independent water and wastes agency
- An efficient, well-staffed, and well-managed agency for technical support that, for communities too small for independent agencies, will: (1) plan programs, provide guidelines and design assistance to local agencies and communities, monitor ongoing programs, evaluate completed projects, and ensure that lessons learned are reflected in new designs; (2) maintain close liaison among design, operating, and maintenance activities; (3) establish clear criteria for selection of materials and equipment; (4) actively promote programs and assist communities in their implementation; and (5) be sufficiently decentralized to assist communities effectively.

Organizational Issues

One of the fundamental decisions to be made in organizing the water supply and sanitation sector is whether the sector should be independent or combined with other municipal or social sectors. Successes and failures have been reported for both organizational approaches, and there are advantages and disadvantages to both solutions. In urban areas there is usually an established organization that is responsible for municipal water supply and waste disposal. In large cities, this is often an autonomous agency, whereas in smaller cities it is frequently a department of the municipality or a part of a multisectoral agency. In either case, the organization has staff competent in conventional water supply and waste disposal technology, although the degree of expertise and the availability of financial resources to develop and implement projects differ from municipality to municipality. Quite often, municipal agencies or departments are assisted by a regional organization or a government agency that is responsible for overall planning and that allocates funds to support sectoral institutions. Occasionally, however, a regional or state agency is responsible not only for the planning but also for the implementation and subsequent operation and maintenance of water and sewer systems in the area of its jurisdiction.

In contrast to urban water supply and sewage disposal, small towns and rural areas are less able to take care of their own needs because their inhabitants are generally not as well off and, therefore, are financially less able to support the institutions capable of providing adequate services. One solution to this problem that has often achieved notable results is the combination of various productive and social components in rural development projects. In such integrated development projects, the water supply and sanitation component benefits from the organization, management, and (possibly) the income of the project's productive components. Nevertheless, these projects often suffer from the same problem encountered with rural water supply and sanitation systems in general: inadequate operation and maintenance that leads to a rapid deterioration of the facilities. As a general rule, a single, sectoral agency that has been organized to provide support to small community organizations is preferable to a multisectoral institution because the organizational, managerial, and personnel needs of the former are likely to be known and more easily met than those of the latter.

Another critical decision to be made in organizing the water and sanitation sector is the extent of centralization or decentralization of control. Whatever the organizational arrangement, there should be a national policy and planning body; national (in small countries), state, or municipal operating agencies for project planning, implementation, operation, and maintenance; and local community units with responsibility for final technology selection, operation, and maintenance. There obviously are many solutions, with the allocation of responsibility dependent on local conditions. Often the reasons for the choice of an organization are historical. For example, state organizations based on political boundaries are more common than agencies based on topographical boundaries (for example, river basin authorities), even though the latter are usually better suited to dealing with sectoral problems. Both the costs and benefits of any suitable organizational set-up should be evaluated before the structure is adopted.

A good organizational structure provides for maximum participation by communities, particularly in the rural areas where social and cultural considerations are important in selecting standards of service and, thus, the sanitation system's construction and operating costs. There appear to be fewer cultural constraints in urban areas, probably because immigrants to the city have already accepted the need to adapt to a different life style. There is no standard form such community participation should take, but chapter 5 of this report provides some guidelines for its design.

Division of Responsibilities

Whether urban or rural, single- or multisectoral, the institutions and agencies involved in water supply and excreta disposal must have a clear division of responsibilities. It is not as important to decide which functions are assigned to each as it is to avoid overlaps and gaps in responsibilities. A generalized example of the various agencies and accompanying functions likely to be involved in water and sanitation program planning and execution is shown in table 7-1.

Obviously, this tabulation represents a single, relatively simple scheme that will have to be adapted to each specific case. It lists technical organizations with a direct involvement in the sector and does not include such related activities as general education, health education, training in personal hygiene, nutrition, health services, and so forth. All these activities are important, however, and the full benefits of water supply and sanitation often cannot be realized without considering them.

Staff development and training programs, for example, must be based on the instruction of selected individuals and should make use of existing educational infrastructure. Thus, the ministry of education plays an important role in the training of staff for the water supply and sanitation sector. The same ministry may also be responsible for health education, nutrition, and so forth. Alternatively, these supportive activities may be the responsibility of the agricultural extension service or ministry of health. Nevertheless, inclusion of these related functions in the simplified schematic of table 7-1 would have complicated the presentation unnecessarily. The important point for planners to remember is the need to consider these intersectoral, organizational issues in both the assignment of institutional responsibilities and the design and implementation of projects. The maximal use of the agency with primary responsibility and expertise in the given area is usually the best solution.

In practice, the organizational arrangements will probably never be as simple, and responsibilities so clearly defined, as indicated in the table. For example, in many countries the responsibility for urban and rural areas is allocated to different ministries. Even within urban and rural areas, there may be different responsible ministries or various agencies within ministries. Furthermore, communities are dynamic. They naturally grow and develop and, thus, can move from one jurisdiction to another.

Ideally, the sector should be properly organized before projects are designed and implemented. It is rarely possible, however, to achieve this objective in

Table 7-1. *Institutional Responsibilities in Sanitation*

Level of institutional responsibility	*Function*
National legislature	Review and approval of policies; establishment of enabling legislation
Ministry of economic planning, hydraulic resources, public works, and the like	Long-term planning; allocation of national and foreign financial resources
Public utility commission (or planning unit)	Planning of policies and sectoral priorities; review of tariffs; development of sectoral manpower
Sectoral finance agency	Financing and financial policies
Ministry of health	Establishment and monitoring of quality standards
State or province	
Public utility department or planning unit	Detailed planning; allocation of state resources
Water supply and sanitation agency or multisectoral development agency	Implementation of national policies; design and construction; monitoring, supervision, and support of local authorities; manpower training; operational and maintenance backup for small systems
Local	
Municipal department or municipal authority	Design;[a] construction;[a] operation and maintenance; on-the-job training
Water and sanitation committee of small community or cooperative	Construction; operation and maintenance

a. Unless performed by the state agency.

practice within a short period of time. The overall organizational objectives of the sector should therefore be considered as long-range goals, with the institutional arrangements that will eventually lead to their attainment (or that, at least, will not prevent their clarification and development) being designed for specific projects and programs.

In sum, it is the finding of this study that the irreducible, minimal institutional requirements for the successful implementation of community water supply and sanitation projects are: a government (national or state) policy that supports the project; a sectoral agency at the regional (for rural areas) or community (for large cities or metropolitan areas) level to provide the project with technical support; and a community organization, committee, or leader to provide the link between users and agency. Although not interchangeable, these required levels of institutional organization are interdependent and reciprocal. Projects and programs can be initiated at any of the three levels as long as they fulfill the requirements of the other two.

Note to Chapter 7

1. For a discussion of water tariff design based on principles of marginal cost pricing, see J. J. Warford and D. S. Julius, "Water Rates in Developing Countries," *Journal of the American Water Works Association* (April 1979), pp. 199–203.

8

Community Participation and Organization

CONVENTIONAL WATER SUPPLY and sewerage projects are usually designed without community participation; that is, the beneficiaries are not directly consulted or involved in the design, implementation, or operation of the facilities. In fact, public involvement is often considered of little value at best and a hindrance to progress at worst. That sanitary engineers get away with this attitude and proponents of nuclear energy, for example, do not is probably because sewerage is an established technology and nuclear power plants are new and controversial. Few members of a community to be served by a new sanitation system ask the question whether the conventional sanitation technology is the best or the only feasible method of providing the intended service.

In the urban areas of developing countries, the lack of community participation has resulted in water and sewerage systems' being constructed according to the models of those built in industrialized countries. This simple adoption of advanced technology has provided reasonable water service to the middle- and upper-income populations and sewerage to those in very dense and high-income areas. The high cost of conventional sewerage, however, has inevitably meant that scanty or no facilities could be provided for the poor. The situation is even worse outside major cities. In rural areas, the lack of funds is made worse by the absence of sectoral institutions capable of operating and maintaining conventional facilities.

Increasing the present low levels of sanitation service will require either a massive infusion of funds and the creation of large service organizations or the use of technologies that are less expensive than sewerage and easier for users and smaller communities to operate and maintain. With funds limited, the use of alternative sanitation technologies clearly offers a greater possibility for realization of this goal, but it will also require greater involvement by beneficiaries in smaller towns and rural areas to compensate for the absence of a strong, centralized institution.

Objectives

The objectives of community participation in sanitation are the selection of:

- Technologies that are acceptable to the community and that offer benefits the community considers important at a cost it can afford
- The most effective materials and methods of constructing the appropriate facilities
- Technologies that can be operated and maintained by the local population with minimal assistance from outside agencies.

To achieve a successful project, the community's participation should extend from the initial collection of data and identification of users' preferences through the design and construction stage to the permanent operation and maintenance of the facilities. The form of participation and the extent of community involvement will vary. A community on the urban fringe (for example, a slum being upgraded) can probably count on the city sanitation organization's providing municipal water and sewerage services to implement and operate communal facilities. Here, community participation will be concerned primarily with the selection of levels of service that reflect the community's needs and willingness to pay. Rural communities, however, need to develop a system they can operate and maintain with a minimum of external assistance. This usually means local, part-time management and operation supplemented by advice and assistance from a regional organization for technical support.

Scope

To achieve the objectives of community participation in sanitation, the organizational program must include:[1]

- Identification of formal or informal channels for community leadership and communication
- Determination of the community's existing practices for water use and excreta disposal and its attitudes toward them
- Determination of the community's willingness to pay for desired improvements through cash contributions, labor, or materials
- Organization and execution of any self-help construction agreed upon
- Operation and maintenance of communal facilities, assistance to users in maintaining individual facilities, and collection of funds.

There are many methods and models for initiating the process of community participation that may be suitable for different communities. Obviously, the approach must fit the particular community, and what is suitable in one culture may not be appropriate in another. Regardless of the agency or organization responsible for initiating sanitation projects, a team including behavioral scientists, community extension workers, and engineers is probably most suitable for implementing a program for community participation. At the least, the team should consist of a technician familiar with low-cost water and sanitation technology and a person (preferably female) with expertise in public health education, personal hygiene, and nutrition. Both should be employees of the agency responsible for providing the community with technical support and should have access to agency specialists such as hydrogeologists, well drillers, engineers, economists, behavioral scientists, health specialists, and the like. The involvement of the community leadership is important for the success of the program regardless of the method used to implement the program.

Implementation

The following tasks can be identified as the minimum for a community participation program that will lead to a successful project. Each will be discussed in turn in this section.

- Unstructured interviews with community leadership and a limited number of users to identify users' attitudes and preferences
- Design and testing of a questionnaire for structured interviews
- Structured interviews conducted with a representative sample of households
- Presentation of feasible technologies and their costs to the community or its leaders to determine willingness to pay
- Organization of the construction and execution of the work
- Continued activities of operation, maintenance, and monitoring, including the assessment and collection of fees.

The first three tasks should be undertaken at the very beginning of project development (they are, incidentally, part of stage 1 in figure 1-1), the fourth toward the end of the selection phase (stage 6 of figure 1-1), and the final two must be scheduled to meet technical requirements and community work patterns.

The first task uses unstructured interviews to determine local attitudes and perceptions that can affect the choice of sanitation technology and engineering design. Among the factors to be considered here are preferences for private or communal facilities; importance of the facilities' location, capacity, reliability, and privacy; the importance of aesthetic features such as the design of the superstructure or color of the interior; local traditions concerning conservation, reuse, or reclamation of water and waste; the importance of local autonomy versus confidence in regional or national authorities; and the existence of cooperative arrangements, either formal or informal. Other factors about which information is essential for design or implementation include: land tenure; the customary manner in which local committees are formed and contributions in time, money, or materials are made to community projects; and the means by which a community majority or consensus can be obtained.

The second task consists of the preparation and testing of a questionnaire for structured interviews. Specific questions are needed to get specific answers. The type of questionnaire used in the World Bank case studies was described in chapter 5, and it can serve as a basis for developing locally relevant questions.

The third task is the formal interviewing of a representative sample of the community. It is not necessary to conduct a census of the entire community if the sample is selected with the cooperation of the community's leaders. Household interviews should include women, since they are both knowledgeable about water use and responsible for training children in personal hygiene and sanitation. The interviewer should always remember that the most reliable answers to questions on sanitation will come from those who are most concerned about sanitation, and these responses will be given most candidly to an interviewer who is perceived to understand and empathize with the respondents. Selection of interviewers from the same population group and with a similar socioeconomic background is therefore extremely important. After the formal interviews, the responses should be evaluated jointly by the behavioral scientist and engineer of the project team. Information collected during the unstructured interviews should be used to put the questionnaires' results into perspective. If, for example, land tenure or employment was found to be a strong priority during the unstructured parts of an interview, sanitation problems will get little attention from the householder.

The information on community preferences and attitudes should be used by the engineer to design acceptable sanitation alternatives. Once these have been costed, a meeting should be held between the project team and the community or its representatives at which the alternative technologies and their costs should be discussed (the fourth task). Photographs and working models should be presented and explained, particularly in areas where written communication is not widely used. The benefits of each level of service and the manner in which each alternative can be upgraded should be discussed. If necessary, limited demonstration projects may be built. In any event, the community's choice of technologies and willingness to pay should be determined at or following this meeting.

If an interested majority within the community does not develop in about a month after the meeting, it will ordinarily be better to shift the project and resources to another community. Important differences between community preference and design or between levels of service (whether higher or lower) are seldom resolved by more education or information, and voluntary schemes in which wealthier individuals are asked to support sanitation services for others usually do not work. For example, wealthy homeowners are not likely to abandon functioning septic tanks and pay high charges for sewer connection so that poor neighborhoods can be served by the same sewer system. Either in parallel with the selection of technology 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 (the fifth and sixth tasks).

The fifth task follows on the selection of technology and is the time when the choice of implementing procedure (for example, self-help labor, contracting, or a mix of the two) and organization is made and the construction is undertaken. Construction work should be performed with the assistance of the technician from the technical support agency (but under local leadership, if possible). For continuity, it is important that the technician train at least one person in the community for this task as the participatory process proceeds.

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

If there is a formal organizational structure in the community, it may be used to facilitate project implementation and operation. If no structure exists, special organizational arrangements will have to be made for the project. Such arrangements can range from the selection of a local craftsman who will periodically check a piece of equipment to the hiring of full-time staff for operating and maintaining a communal facility. Just as in the selection of the technology, the type of organizational arrangement should be a community decision.

The sixth task encompasses the regular operation, maintenance, and monitoring of the facilities. The monitoring program should include the dissemination of the information collected for the project to other communities, so that lessons learned from the success or failure in one location can be used in the design and implementation of programs in others. The monitoring should also include the exchange of visits by those responsible for the operation and maintenance of similar facilities in various other communities and, if systems are large or sophisticated enough, the training of local personnel at regional agency headquarters. Any training not accomplished under the fourth and fifth tasks above should take place now, and the relation between the operators and the technician should be established. The technician should make periodic visits to the community to help solve minor problems, provide routine technical assistance, order spare parts, and mobilize additional support if major problems arise. These visits should be regular and made at short intervals in the beginning of operations and at least once a month after the community has become familiar with the tasks of operating the facilities. Provision also should be made for rapid contact in cases of emergency (such as the failure of equipment, suspected water contamination, and the like).

Linkage of the Institution and Community

As the preceding description of tasks suggests, many aspects of the community's participation in sanitation program development depend upon and influence institutional structures. Although the previous chapter dealt specifically with institutional issues, it may be useful to conclude this chapter with a simplified description of the institutional steps required to facilitate and support community involvement. These policies should include measures to:

- Establish a support unit for water supply and sanitation in existing regional agencies or form an independent support unit (the specialists likely to be involved include engineers, hydrogeologists, a behavioral scientist, an economist, an accountant, a plumber, a mechanic, an electrician, a well driller, a purchasing agent, and a health educator)
- Organize and staff a central support unit; establish design and operating standards and select the villages or the criteria by which priority is assigned; conduct specialized tasks such as hydrogeological surveys, management training, or operating assistance
- Train community workers in low-cost technologies for water supply and sanitation and in community organization
- Train community workers in health care and nutrition
- Canvass and organize selected communities; plan, design, and implement prototype projects to complete the training of community workers
- Assign community workers or teams to designated areas to canvass and organize communities
- Assist communities in constructing facilities
- Maintain a limited number of community workers as itinerant maintenance and operations advisers and monitors for completed projects; assign all other extension workers to new areas to replicate successful projects
- Provide technical assistance and support; maintain the stock of spare parts
- Monitor the operation and quality of service; disseminate information; and provide continuous training programs for community workers and local staff.

In sum, community participation and the assessment of a community's willingness to pay for improved service levels through contributions of money, labor, or materials depend fundamentally upon household income levels and perceived needs. This assessment is affected by the accuracy, completeness, and timeliness of the information that is exchanged between the residents and those who are conducting the feasibility study. Analysis of social factors and the conduct of interviews should be the responsibility of community members or people accepted by the community; these tasks are too important to be entrusted to strangers.

Note to Chapter 8

1. This list has been developed in part from work by A. U. White and G. F. White, "Behavioral Factors in Selection of Technologies," in *Appropriate Technology in Water Supply and Waste Disposal*, ed. Charles G. Gunnerson and John M. Kalbermatten (New York: American Society of Civil Engineers, 1979). pp. 31–52.

9

Project Development

WITHIN THE FRAMEWORK for institutional and community involvement in the planning of sanitation programs discussed in previous chapters, the development of individual sanitation projects will be accomplished by different approaches in different settings. This chapter considers three of the most probable settings for project development and presents a method for the selection and upgrading of technology.

Types of Sanitation Projects

The urban or rural setting for a sanitation project, as well as the particularities of the site, will influence the choice of appropriate technology (see chapters 1 and 2). Similarly, the institutional structure through which an urban sanitation project is developed and implemented will be different for a project designed specifically for water supply and sanitation and for one designed for general urban development. These differences will be examined in the following subsections.

Urban water supply and sewerage

Conventional sanitation projects are usually developed through well-defined stages, beginning with a master plan for an urban community or region. Such a plan generally defines stages of implementation and is followed by feasibility studies for individual stages or projects, which are followed in turn by detailed design and construction. All these studies and designs can be done by the sanitation institution, although the work is more often contracted to consulting engineers. Construction of small projects is often performed by the sectoral agency, whereas major projects are generally constructed by contract, with only the supervision of construction provided by agency staff.

Community participation in conventional water supply and sewerage projects is minimal. Projects are generally designed to satisfy existing or forecasted demands, and the solution employed is usually so well known and universally accepted that any discussion of alternative technology is not considered necessary. Rarely, if ever, is a community consulted on the level of service to be provided, and decisions are usually made by the agency or the municipal government.

The major drawback of conventional projects has been their cost, which effectively has prevented the extension of water supply and sewerage services to all inhabitants of a community. Usually the downtown areas and middle-class districts of cities are the first recipients of water supply and sewerage services. Water supply at a lower level of service (for example, public standpipes) is often extended to other areas of a city, but sewerage is rarely, if ever, constructed in districts other than the high-density areas during the first stages of a master plan's implementation. This state of affairs is a reflection both of the high cost of sewerage (and its requirement for water connections) and the prevalent attitude that the only acceptable method of excreta disposal is waterborne sewerage. People unable to pay the high cost of sewerage simply have to forgo the service.

To serve the entire population of a community at a price it can afford, a change is required in the development of master plans for sanitation. Terms of reference should specifically require that consultants evaluate not only the potential development of sewerage for some areas but also the provision of sanitation services for the entire community. This change in planning will identify areas for which sewerage is the correct solution and areas for which other methods of sanitation are appropriate. These latter alternative sanitation services should be designed to be gradually upgraded as water consumption increases and the incomes of the users grow. Therefore, a master plan should provide for the implementation of waste disposal systems for an entire urban area, identifying not only the various stages of a sewerage scheme for affluent and downtown areas but also the appropriate sanitation technologies and their upgrading sequences for other areas of the city. Similarly, the water supply component should provide for a mix of service standards that can be gradually improved as the demand from, and the financial resources of, consumers increases.[1]

A major departure from the traditional approach to the development of urban water supply and sewerage systems is the requirement that the master plan consider several technologies and that the subsequent feasibility, design, construction, and operating stages reflect the progress over time of each of the alternative technologies to be used. Another, additional revision of previous practice is that, in the selection of alternative sanitation technologies, the community to be served be included in the choice of a technology that will match its preferences and needs. Organizing the community for operation and maintenance of the chosen technology will ordinarily not be required because the existing municipal organization should be capable of providing the necessary services.

Preparation of such a master plan obviously requires additional and different skills, and consultants should be selected and compensated accordingly. Consultants need to have on their staff specialists in the behavioral sciences, community organization, economics, sanitation, public health, low-cost construction, and personnel training. This last specialist will have to devise and implement training programs for local staff, so that they acquire the skills necessary to undertake similar projects elsewhere in the region. Most consultants will initially have to train their own staffs in the design of nonconventional sanitation projects.

Urban development

Urban water supply and sewerage are provided not only by agencies directly responsible for these sectors but also by a variety of organizations responsible for the design and implementation of multisectoral projects—such as urban development, slum upgrading, development of satellite communities, and the like. Responsibility for the provision of water supply and sewerage for such projects may rest with a municipal water and sewerage agency, which will likely follow its established procedures for project development and implementation. Alternatively, a development agency may design and implement the project independently or work under various cooperative arrangements with a water supply and sewerage institution.

Whatever the institutional arrangements, a multidisciplinary project would, ideally, implement already defined sectoral plans. But very often sectoral plans do not exist (see chapter 7) or do not cover all the areas involved. Some ad hoc sectoral planning must then be done so that future integration of the facilities into a municipal network can be accomplished at least cost. Whether a water supply and sewerage agency should provide planning and implementation services to the multisectoral project, or whether the project should do its own planning and implementation with the help of consultants, must be decided for each individual case. In any event, it is best that the municipal water and sewerage agency be responsible for operation and maintenance after the system is put into service.

One of the distinguishing features of urban development projects—and particularly of "sites-and-services"[2] and slum-upgrading projects—is the active participation of the community. This participatory process can easily be extended to include water supply and sanitation. As in previously described projects, community participation would be primarily in the selection of technology rather than in the organization of operation and maintenance. An exception is the case in which a new community must provide its own infrastructural services. In this case, of course, the process of community participation will have to include the establishment of the necessary organization for operating and maintaining communal sanitation facilities.

Rural water supply and sanitation

The provision of water supply and sanitation to rural areas has traditionally been the most intractable problem in the sector, basically because rural communities are too small to support their own viable infrastructural agencies. Rural areas also have often been neglected in national or regional planning for water supply and sanitation. An additional reason for the neglect has been that the technologies for water supply and sanitation have been developed primarily for the benefit of urban populations. In sanitation technology particularly, a gap exists today between what is affordable in a rural community and what is provided as standard practice in the urban community. Because urban communities more often contain a mix of income levels than do rural ones, the potential for cross-subsidizing poorer residents is lower in rural communities.

For lasting success, projects for rural water supply and sanitation require the government's commitment, an agency to provide technical support, and community participation. It takes time, of course, to translate governmental support into effective policies and direction, and it also takes time to establish an effective organization for technical support at the regional level. A judgment has to be made in each case on how far the process of translating the government's commitment into substantive action and of implementing an organization for technical support must proceed before communities can be helped in their desire to improve their water supply and sanitation services. The type of sanitation technology to be used has an important bearing on this judgment because, if only minimal funding and technical support will be required, then assistance to the community plays a less important role in the project's eventual success. In any case, great care has to be taken not to raise expectations that may not be fulfilled.

Rural water supply and sanitation projects require a comprehensive governmental policy on how rural needs for infrastructure are to be met and financed. Criteria for the selection of communities and for standard project design should be established by the technical support agency responsible for the area in question. Based on these policies and criteria, the technical support agency should train community workers in appropriate water supply and sanitation technology, health education (particularly personal hygiene), and nutrition. In addition, the community workers should receive comprehensive training in how to generate community participation and how to organize a community in the implementation and subsequent operation and maintenance of the facilities.

Technology Selection

In the foregoing section, three standard settings for sanitation projects were described. In the sections that follow, information presented in preceding chapters will be used to develop an analytical method for the design of sanitation projects in a particular setting and sequences for modifying appropriate technology to meet users' changing needs for improved service.

Once a community has been selected for sanitation improvements, the planner of sanitation projects must select from those technologies appropriate to the needs and resources of the community. This selection should be based on a combination of economic, technical, and social criteria, and these issues often reduce to the single question: what is the least expensive, technically feasible technology that the users will accept and can maintain and that the local authority is institutionally capable of operating? This question may not pertain in communities (or areas of cities) with higher income levels, in which consumers may prefer and be willing to pay for higher service standards. The cheapest technology may not always be the one that should be chosen, but it certainly must be determined if the full range of alternatives is to be explored.

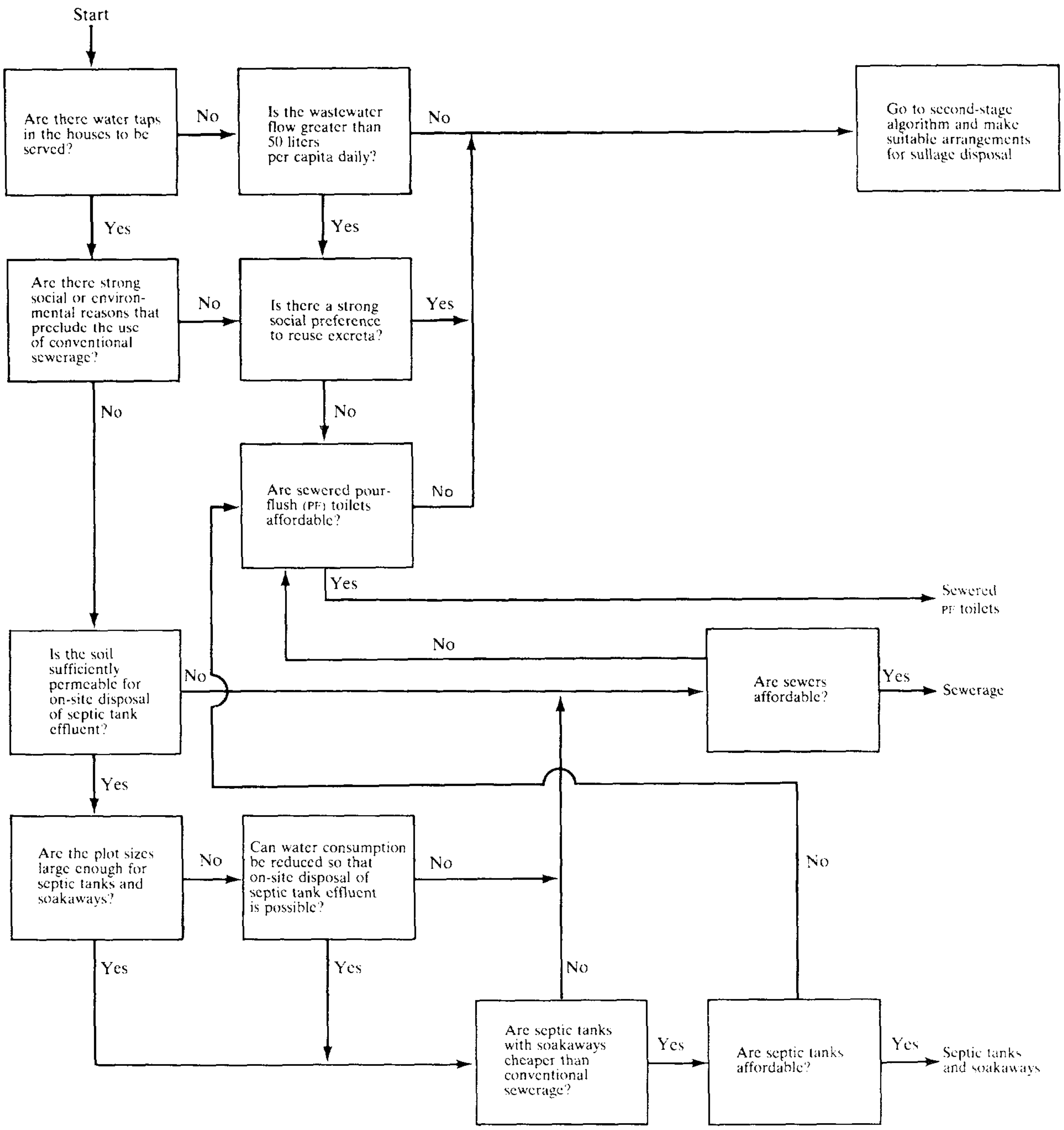
An algorithm, which can be used as a step-by-step guide to the selection of the most appropriate sanitation technology for any given community in the developing countries, is presented (in stages) throughout figures 9-1 through 9-3. The algorithm is intended only as a guide to the decisionmaking process. Its main virtue is that it can stimulate engineers and planners to ask the right kinds of questions, the sort they may not ask otherwise. Some of the answers to these questions can only be obtained from the intended beneficiaries (see chapter 8). Although it is believed that the algorithm is directly applicable to most situations encountered in developing countries, there will always be the occasional combination of circumstances for which the most appropriate option is not the one the algorithm suggests. This analytical device should not, therefore, be used blindly in the place of engineering judgment but, rather, as a tool for facilitating the critical appraisal of various sanitation options, especially those for the urban and rural poor.

The algorithm is most useful when there is no existing (formal) sanitation in the community under consideration. In general, any existing household sanitation systems, except perhaps unimproved pit and bucket latrines, will influence the technology chosen to improve excreta and sullage disposal in ways the algorithm cannot fully capture. In addition, it is important to consider the sanitation facilities existing or planned in neighboring areas because these facilities may enable the community to reduce its costs below what they would otherwise be, thereby providing additional affordable alternatives. Here and in the algorithm, affordability is taken to embrace both economic and financial affordability at the household, municipal, and national levels—including the question of subsidies—as discussed in chapter 3.

The selection process starts, in figure 9-1, by asking if there is, or soon will be, water supply service to the houses under consideration. This is a critical question, since its answer immediately determines whether conventional sewerage is a possible option or not. If the water supply service is through house connections, if there are no social or environmental reasons for excluding sewerage, and if it can be afforded—then conventional sewerage is chosen (unless there is sufficient land and less cost for septic tanks with soakaways). Septic tanks with drainage fields would be the technology of preference where water-saving appliances—such as cistern-flush toilets using less than 1 gallon (3.8 liters) of water—can be installed to make them feasible.

If a community does not have, and is not likely to have, house water connections, then cistern-flush toilets and conventional sewerage cannot be used. If

Figure 9-1. *First-stage Algorithm for Selection of Sanitation Technology*



sullage generated on site is sufficient (>50 liters per capita daily) to enable a sewered pour-flush (PF) system to function satisfactorily, a sewered PF system can be used provided that: it is cheaper than alternative systems with separate sullage disposal facilities or the users, or the municipality are willing to pay the extra cost, and there is no overriding social preference for night soil to be collected separately for subsequent use. If the sewered PF system is not appropriate, the choice lies among the various on-site excreta disposal technologies with appropriate facilities for the disposal of sullage (see the selection process for these in figure 9-2).

If double-vault composting (DVC) toilets and three-stage septic tank systems cannot be used, the choice lies between ventilated improved pit (VIP) latrines, Reed Odorless Earth Closets (ROECs), PF toilets, vault toilets, and communal sanitation blocks as determined by the algorithm in figure 9-3. The advantages and disadvantages of these technologies and their applicability under different conditions have been discussed in chapter 2.

Once the most appropriate technology has been selected by using the algorithm, several questions should be asked as checks. These are:

- Can the existing sanitation system (if any) be upgraded in any better way than that suggested by the algorithm?
- Is the proposed 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 (for example, education and inspection) required? Can they be made available?
- Is the technology politically acceptable?
- Are the consumers willing to pay the full cost of the proposed technology? If not, are user subsidies (direct grants or "soft" loans) available? Is foreign exchange required?
- What is the expected upgrading sequence? What period of time is involved? Is it compatible with current housing and water development plans? Are more costly technologies in the upgrading sequence affordable and desired now?
- 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?
- If the technology cannot dispose of sullage, can adequate facilities for sullage disposal be installed? Is the amount of sullage low enough (or could it be reduced) to avoid the need for sullage disposal facilities?

Sanitation Sequences

The selection of the technology best suited to effect initial improvements in sanitation for a particular area has been discussed in the preceding section. This selection should, however, also reflect the future need for improvements as the users' aspirations and socioeconomic status rise. The following subsections examine the feasibility of upgrading sanitation in stages that take into account incremental improvements in the level of water supply service (improvements that are themselves, of course, measures of socioeconomic status). Such feasible sequences, or stages for upgrading, are summarized in figure 9-4.

DVC toilets and three-stage septic tanks

These toilets, functioning well and with a continuing demand for compost or fertilizer, need no upgrading. Upgrading of the water supply from hand-carried to household service, increased housing density, or decreased demand for compost would, however, require modifications in these facilities. The toilets could be easily modified to PF vault toilets or to vaults with vacuum-truck collection.

VIP latrines and ROECs

Many rural and suburban water and sanitation projects provide pit latrines and communal handpumps or public standpipes as the initial improvement. The pit latrine should be either a VIP latrine or ROEC. The subsequent priority for improvement would most likely be upgrading the water supply to yard taps (or household handpumps where applicable). Both the VIP latrines and ROECs could then be upgraded to PF toilets. The conversion of a ROEC to a PF toilet is very simple and inexpensive: a water-seal squatting plate or pedestal seat is installed in place of the ROEC chute, and the existing displaced pit is used to receive the flush water. Depending on soil conditions it may be necessary to enlarge the pit to provide more infiltration area for the flush water. Alternatively, a second pit or infiltration trench could be provided to receive the settled flush water from the original pit.

A VIP latrine can also be converted to a PF toilet by filling in the pit with soil and installing a water-seal unit that is connected to a newly dug pit. Clearly, this is best done when the pit is close to the end of its life, and it is most advantageous when the superstructure cannot easily be dismantled (for example, the superstructure is constructed in concrete block or adobe brick).

PF toilets

When the water supply is upgraded to house connections, 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 house connections usually first means plumbing for kitchens and bathing areas. The main improvement required is better sullage disposal that does not have to be via sewers. One such conversion requires:

Figure 9-2. *Second-stage Algorithm for Selection of Sanitation Technology*

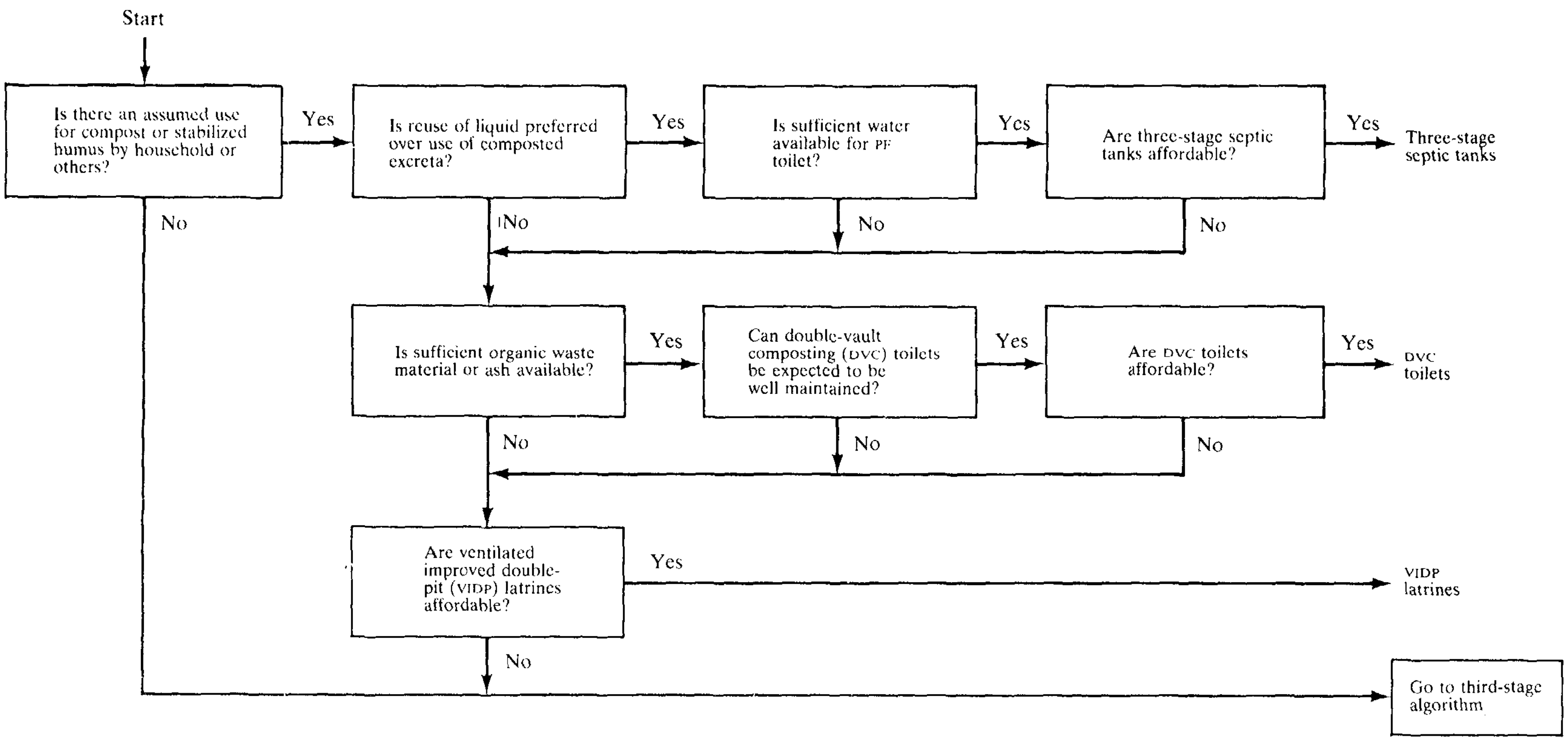


Figure 9-3. *Third-stage Algorithm for Selection of Sanitation Technology*

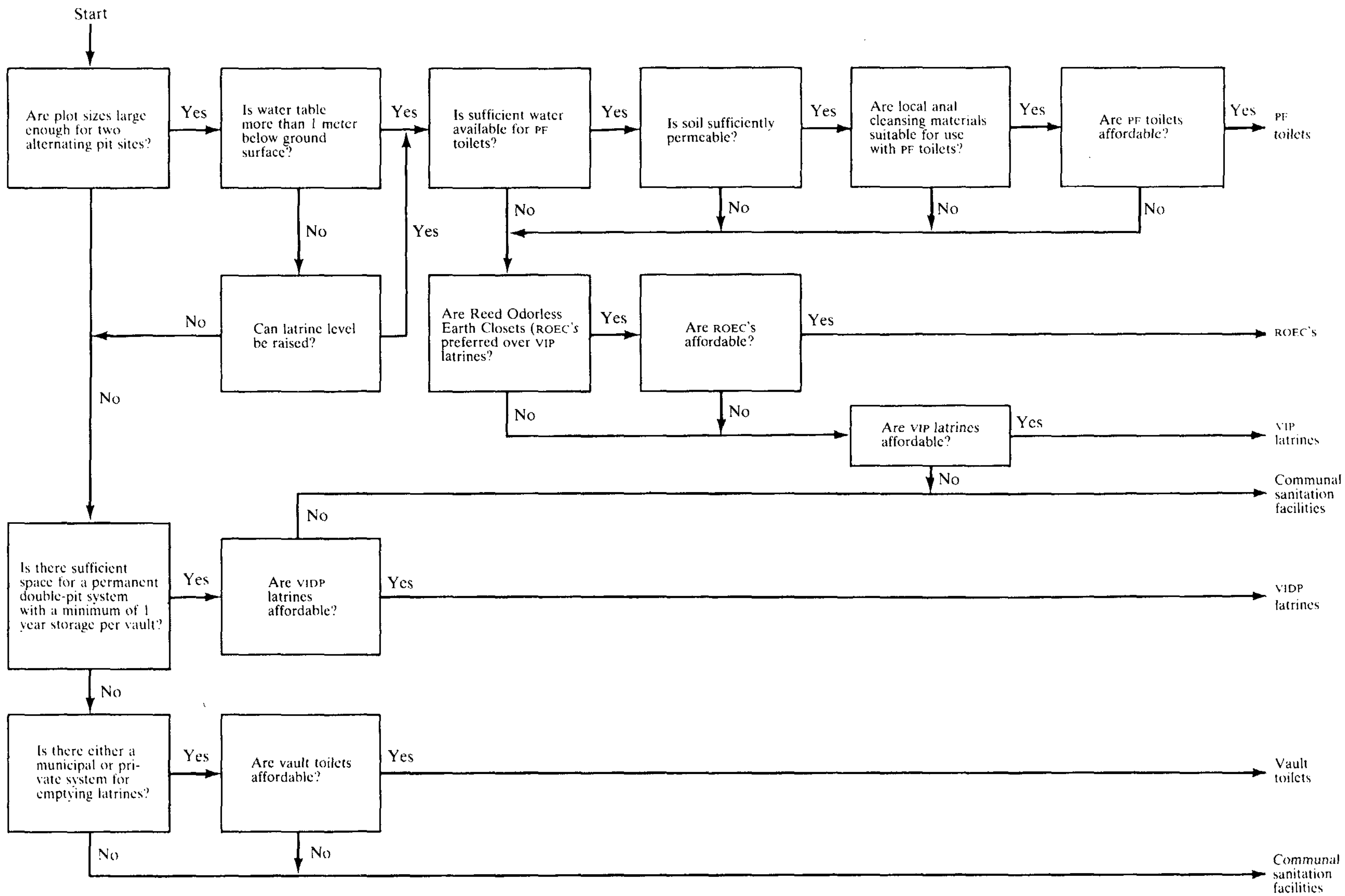
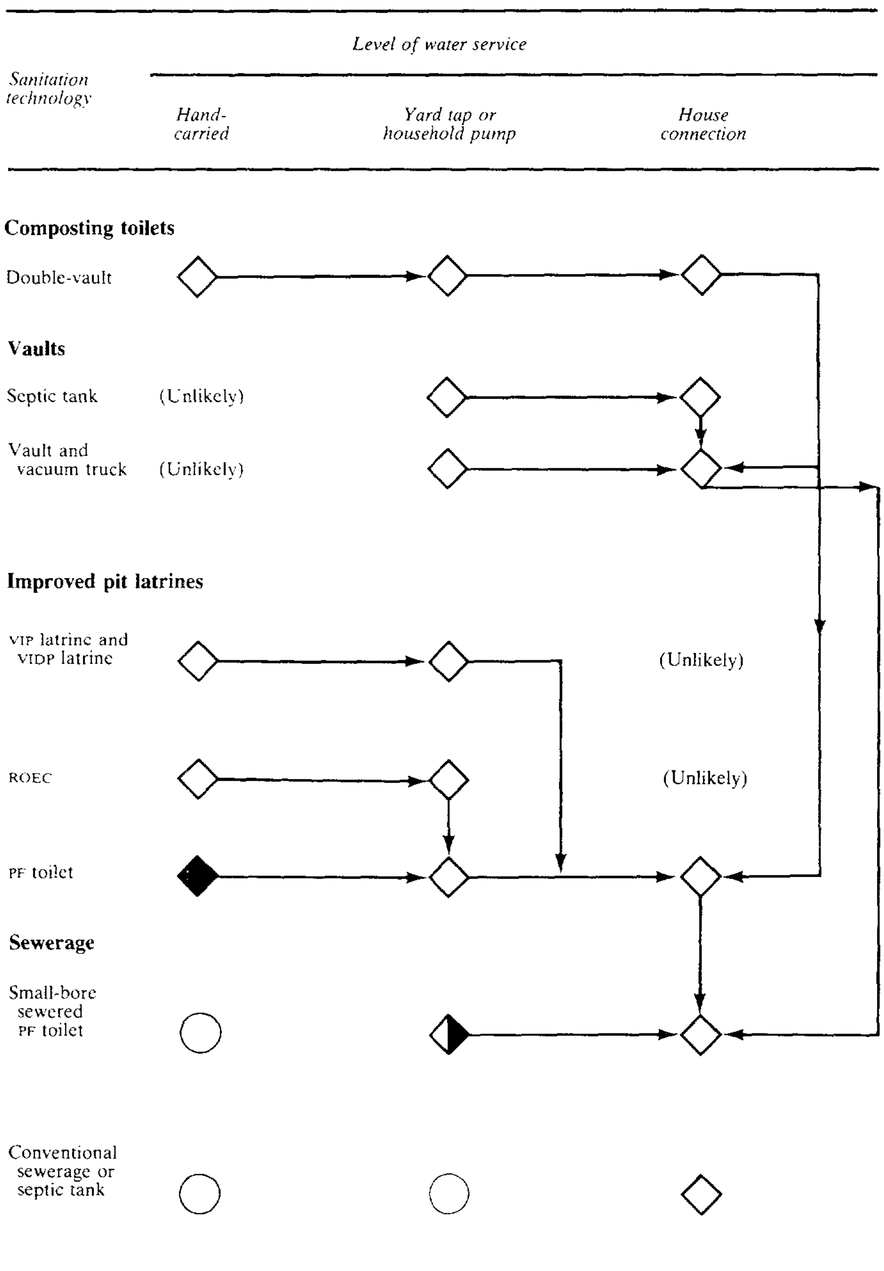


Figure 9-4. *Potential Sanitation Sequences*



◇ 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.

- Construction of a small, single-chamber septic tank close to the existing PF pit and discharge of the sullage directly into it (the tank should provide twelve hours of retention time, subject to a minimum working volume of 0.5 cubic meters)
- Connection of the existing PF pit to the sullage tank with pipe 100 millimeters in diameter (the pit outlet "tee" junction should be located as near the top of the pit as technically feasible)
- Connection of the sullage tank to the street sewer (the invert of the tank outlet should be a nominal 3 centimeters *below* that of the inlet from the PF pit to prevent sullage from flowing into the PF pit) or to the soakaway.

If the existing PF pit has sufficient infiltration capacity, there will be little or no flow from the pit to the sullage tank. This does not matter—in fact, it will improve the functioning of the soakaway. But as the infiltration capacity falls—and especially if cistern-flush toilets are installed—the flow will increase, and the pit will act as a sealed or semisealed first compartment of a two-stage septic tank. It is essential that the sullage tank (the second compartment of the two-stage septic tank) is provided; otherwise, the small-bore flat sewers (or the soakaway) will become blocked.

Vault toilets

The system of vault toilets and vacuum trucks is used most commonly in urban areas. Because the vault satisfactorily stores the excreta and PF water and has a water seal, no upgrading is necessary for excreta disposal. As the water supply service improves to a house connection, however, sewers or other suitable arrangements for sullage disposal may be desirable. If sewers are installed, the vault toilet may be readily converted to a sewered PF toilet by connecting the vault to the sewer system as described above.

Sample Staged Solutions

To demonstrate the feasibility of using a staged sanitation system, four possible schemes or variations are illustrated in figure 9-5, and comparative economic costs are presented for each. The last scheme, installation of a sewerage system with no preceding stages, is obviously not a sequence but is included in the figure as a reference. Schemes 1-3 can be started with any stage and terminated at any point, depending on the desires of the users. For simplicity, it is assumed that each stage within a scheme will remain in service for ten years, after which either the next stage will be added or the existing facility will be replaced or repaired. In addition, the schemes described can be varied substantially without adding greatly to the cost. For example, to a standard pit privy with a PF, a vault 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 an aquaprivy or PF toilet with a vault.

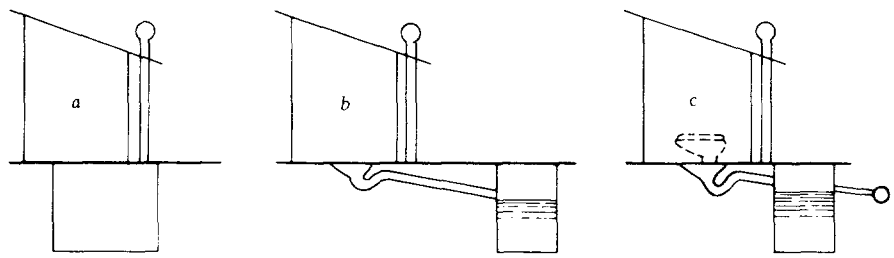
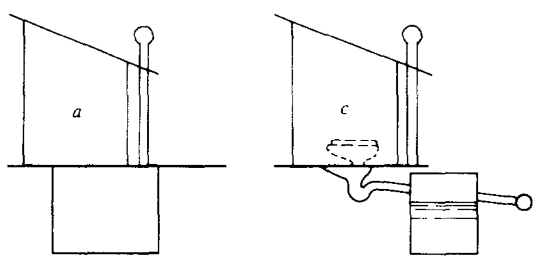
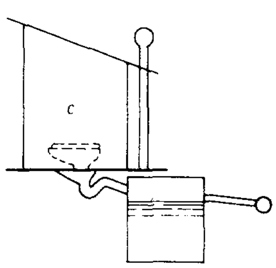
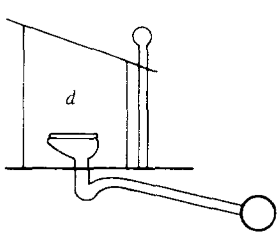
As shown in figure 9-5, the initial sanitation facility (*a*) would consist of a VIP latrine with a concrete squatting slab and concrete block superstructure. An actual facility of this kind in an East African city was used as the basis for the costs shown. Its unlined pit is about 5.5 meters deep and 1 meter square, and the normal filling time is ten years. 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 standpipes to yard hydrants, and the dry latrine is converted to a PF latrine (*b*) by digging a new soakage pit near the superstructure and replacing the old squatting plate with a bowl and inverted siphon. The old pit is filled in prior to placement of the new squatting plate. For costing purposes, it is assumed that the accumulated sludge would be removed from the new pit at five-year intervals and composted.[3] The costs of trucks, land, and equipment for the composting facility are therefore included in year 15, and the trucks are replaced at five-year intervals thereafter. The operating and maintenance costs incurred in years 11–20 also included the cost of water for flushing the PF latrine, which was calculated as 10 liters per capita daily for six persons at $0.35 per cubic meter.

In year 21 the third stage of scheme 1 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 (*c*). 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 a trickling filter plant would be constructed for treatment of the effluent.[4] The combined flushing water and sullage flow from year 21 onwards is taken to be 175 liters per capita daily.

Comparative total economic costs, on a household basis, were prepared for this scheme and for the three variations—including the alternative of proceeding immediately with the construction of a sewerage system (scheme 4).[5] The total economic cost per household of the three stages of scheme 1 over a thirty-

Figure 9-5. *Sample Sanitation Sequences*
(costs in 1978 U.S. dollars)

Item	*Year 1*	*Year 10*	*Year 20 / Year 30*	*Total present value economic cost per household over 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 VIP latrine.
b PF toilet with soakaway.
c PF toilet with small-bore sewer (with optional bowl and seat).
d Conventional sewerage.

year period (in 1978 prices) is $354, which includes the salvage value of the sewerage system (assumed to have a forty-year life). The second scheme shown in figure 9-5 moves directly from the VIP latrine (installed in year 1) to small-bore sewers (in year 11). The total cost per household over thirty years for scheme 2 is $1,111, or more than three times that of the preceding three-stage alternative. The third alternative (scheme 3) is simply the installation of a small-bore sewerage system in year 1. This would have a total cost of $1,519 per household over thirty years. The final alternative (scheme 4), for comparison calculated in the same way and with data from the same city as the small-bore sewerage system, is the immediate construction of a conventional sewerage system. A construction period of five years is assumed, and the facility is assumed to be two-thirds utilized upon completion and fully utilized ten years after completion. Based on these assumptions, the total cost per household over thirty years is $3,000, which includes the cost of water for flushing 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 1 and almost twice that of the one-stage sewered PF alternative shown as scheme 3.

Another alternative to these upgrading schemes would be to move from the VIP latrine to a vault toilet with vacuum-truck collection in year 11. Based on costs from such a system in a city on the island of Taiwan, the total cost per household over thirty years would be $334. If in year 21 it was decided to convert from vacuum collection to a small-bore sewerage system (as described in the previous schemes), the total cost would increase to $411 per household. These costs are summarized in the following tabulation:

	Total economic cost per household (U.S. dollars)
VIP–vault collection	334
VIP–vault collection–small-bore sewer	411
VIP PF–small-bore sewer	354
VIP–small-bore sewer	1,111
Small-bore sewer	1,519
Conventional sewerage	3,000

As is shown in figure 9-5, none of the upgrading sequences discussed above leads to conventional sewerage. This is not because conventional sewerage systems should not be built (they are an excellent form of sanitation for those who can afford them and who have plenty of water), but because they are not necessary to provide a high standard of sanitation. The sewered PF system (which can include a low-volume, cistern-flush toilet for users' convenience) yields an equally high standard of service and has two major advantages over conventional sewerage: it is substantially cheaper, and it can be reached by the staged improvement of several different sanitation technologies. Thus, planners of sanitation programs can confidently select one of the low-cost technologies in the knowledge that, as socioeconomic status and sullage flows increase, it can be upgraded in a predetermined sequence of incremental improvements to an ultimate level of desired convenience. The important fact for concerned planners 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 crucial element of 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.

Notes to Chapter 9

1. See Donald T. Lauria, Peter J. Kolsky, and Richard N. Middleton, *Appropriate Technology for Water Supply and Sanitation*, vol. 9, *Low-Cost Design of Water Distribution Systems* (Washington, D.C.: The World Bank, 1980).

2. Sites-and-services projects generally provide streets, water supply, sanitation, and other basic infrastructure for an urban area; loan funds are made available to potential residents who build their own houses.

3. In some communities, sludge may be buried rather than composted.

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

5. This is the present value (assuming an opportunity cost of capital of 10 percent) of the thirty-year investment and maintenance cost streams.

10

A Concluding Note

IN A SPECIAL SESSION on November 10, 1980, the United Nations General Assembly declared the 1980s the International Drinking Water Supply and Sanitation Decade. The objectives of the Decade—as promulgated by the nations participating in the United Nations Water Conference in Mar del Plata, Argentina, in April 1977—are to provide an adequate supply of safe water and facilities for the sanitary disposal of waste for all by 1990, if possible, or to reach such goals as governments consider feasible. At the General Assembly meeting, governments also submitted national plans for the Decade that indicated targets to be reached and described actions to be taken during the Decade.

If the Decade is one of action, rather than words —and preparatory activities since 1977 by both governments and international organizations active in the sector suggest that serious efforts will be made to make the Decade a success—significant improvements can be effected in the provision of water supply and sanitation services to the inhabitants of developing countries. The success of the Decade will depend primarily on finding effective ways to bring service to the poor. Women and children, in particular, suffer most from a lack of these services because they can least afford them, nor can they afford to protect themselves from infection or to seek a cure for sanitation-related disease.

The design of water supply and sanitation services affordable by the poor initially requires a reexamination of existing technologies that emphasize convenience rather than health benefits. This emphasis on convenience is not surprising, given that the greatest progress in developing sanitation systems in the past, a topic examined in this appraisal, occurred in Great Britain and the United States at a time when the economies of these countries were most productive and their populations could afford to pay for "luxury" sanitation. Consequently, it also is not surprising to find that these systems are too expensive for universal use in the developing world, where scarce resources must be carefully allocated to satisfy basic needs. The reexamination of technologies must, therefore, include a review of their development, and efforts must be made to identify those traditional technologies which are no longer, or only rarely, used in industrialized countries but which could be improved or adapted elsewhere to provide the health benefits of sanitary disposal of waste at significantly reduced cost.

This study has identified and evaluated traditional technologies found in a variety of communities and countries around the world. Costs and benefits have been assessed and improvements suggested. A method of sequential improvement of sanitation has been developed to permit a gradual increase in the level of convenience from the pit privy to a flush toilet in steps that keep pace with the users' ability to pay for them. Incremental costs are low because each step in the sequence makes use of previously built facilities. The study further examines institutional and engineering aspects of sanitation systems and has provided detailed recommendations on how to evaluate sanitation needs, design and implement projects, and organize the necessary institutional and community support.

In demonstrating the feasibility of using low-cost technologies appropriate to the conditions in large and small communities of developing countries, this appraisal can play a significant role in the implementation of the International Drinking Water Supply and Sanitation Decade. Similarly, companion volumes addressing specific topics or reporting case studies provide the planner, engineer, and community worker with detailed information on the design, implementation, and implications for health of sanitation projects. (See the list of publications in the World Bank series on water supply and sanitation given in the preface.) Nevertheless, these publications are but a beginning in the process of designing appropriate solutions to the pressing needs of the world's poor for water supply and sanitation. The next steps are equally important:

- Economic planners and officials responsible for the allocation of international funds must be informed of the availability of appropriate technologies that permit the provision of services to many more people for the same cost as conventional technologies provide services to fewer users.

- Engineers must learn to use these technologies and seek the participation of behavioral scientists and health educators to help in the design of projects fully responsive to the needs of the users and in the implementation of such projects with the affected communities' participation.
- Master plans for water supply and sanitation should provide service standards (and technologies) that the different groups in the community can afford and that include the possibility of adding future sequential improvements. Professionals developing water plans and projects should be recompensed for the work to be done rather than on the basis of the cost of their proposed solutions.
- Work must continue on the improvement of traditional technologies, the adaptation of advanced technologies, and the development of health education techniques so that water supply and sanitation services may be extended at lowest possible cost. For example, upflow anaerobic filters may extend on-site disposal, or sullage water discharge to drains, to many areas heretofore considered unsuitable for the on-site disposal of wastewater.

The list above is, of course, incomplete. But, given imagination and the courage to examine and recommend the unconventional, low-cost solutions to problems of water supply and sanitation will be found. This study represents an initial step in this creative process. It is the hope of the authors that it will stimulate others to join the effort and, thus, to ensure the International Drinking Water Supply and Sanitation Decade's success.

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Index

Page numbers in italics indicate maps, tables, or illustrations.

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The United Nations has designated the 1980s as the International Drinking Water Supply and Sanitation Decade. Its goal is to provide two of the most fundamental human needs—safe water and sanitary disposal of human wastes—to all people.

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