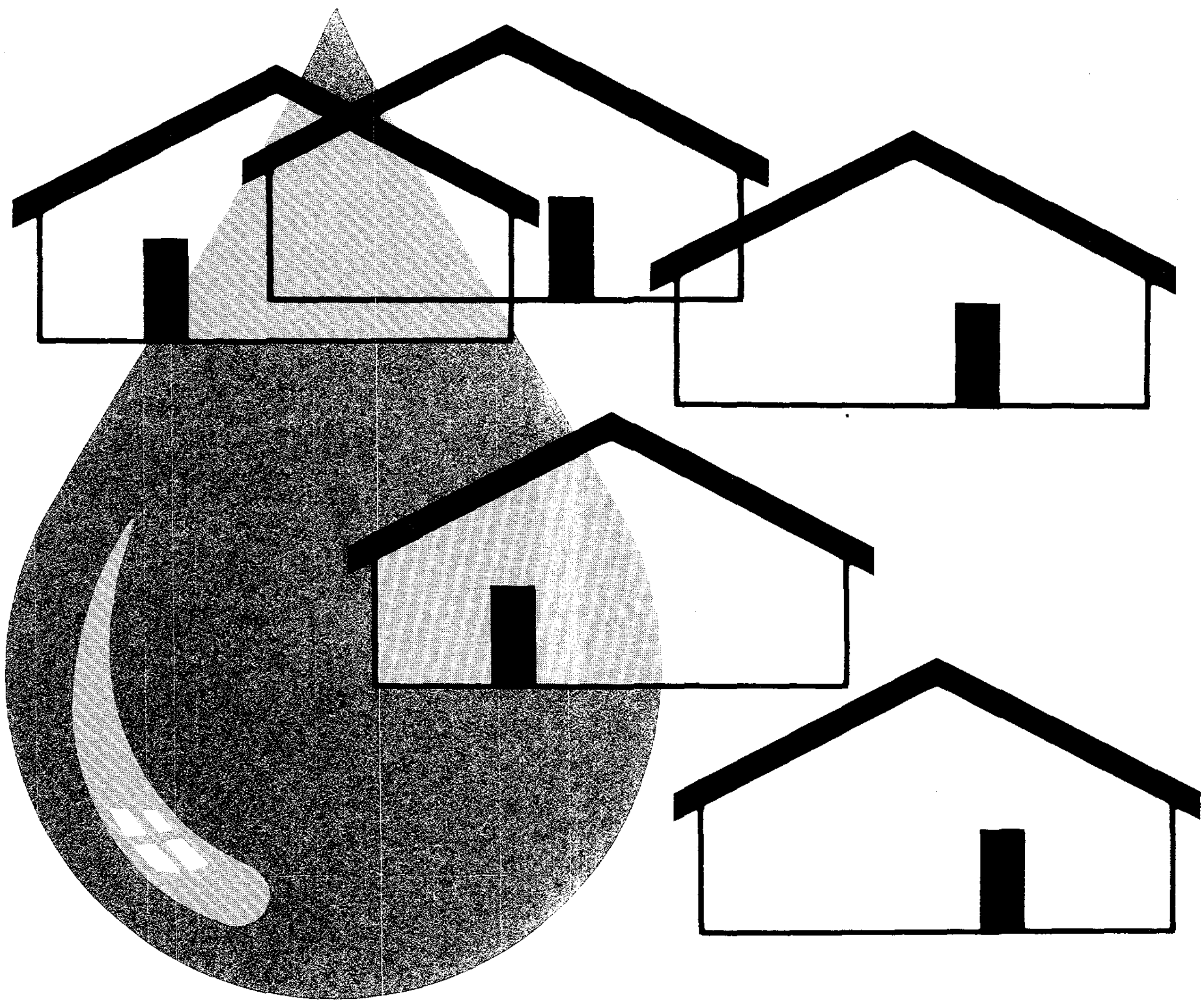
WORLD BANK TECHNICAL PAPER NUMBER 60

WTP60
April 1987

Community Piped Water Supply Systems in Developing Countries

A Planning Manual

Daniel A. Okun and Walter R. Ernst



WORLD BANK TECHNICAL PAPERS

No. 1. Increasing Agricultural Productivity

No. 2. A Model for the Development of a Self-Help Water Supply Program

No. 3. Ventilated Improved Pit Latrines: Recent Developments in Zimbabwe

No. 4. The African Trypanosomiases: Methods and Concepts of Control and Eradication in Relation to Development

(No. 5.) Structural Changes in World Industry: A Quantitative Analysis of Recent Developments

No. 6. Laboratory Evaluation of Hand-Operated Water Pumps for Use in Developing Countries

No. 7. Notes on the Design and Operation of Waste Stabilization Ponds in Warm Climates of Developing Countries

No. 8. Institution Building for Traffic Management

(No. 9.) Meeting the Needs of the Poor for Water Supply and Waste Disposal

No. 10. Appraising Poultry Enterprises for Profitability: A Manual for Investors

No. 11. Opportunities for Biological Control of Agricultural Pests in Developing Countries

No. 12. Water Supply and Sanitation Project Preparation Handbook: Guidelines

No. 13. Water Supply and Sanitation Project Preparation Handbook: Case Studies

No. 14. Water Supply and Sanitation Project Preparation Handbook: Case Study

(No. 15.) Sheep and Goats in Developing Countries: Their Present and Potential Role

(No. 16.) Managing Elephant Depredation in Agricultural and Forestry Projects

(No. 17.) Energy Efficiency and Fuel Substitution in the Cement Industry with Emphasis on Developing Countries

No. 18. Urban Sanitation Planning Manual Based on the Jakarta Case Study

No. 19. Laboratory Testing of Handpumps for Developing Countries: Final Technical Report

No. 20. Water Quality in Hydroelectric Projects: Considerations for Planning in Tropical Forest Regions

No. 21. Industrial Restructuring: Issues and Experiences in Selected Developed Economies

No. 22. Energy Efficiency in the Steel Industry with Emphasis on Developing Countries

No. 23. The Twinning of Institutions: Its Use as a Technical Assistance Delivery System

No. 24. World Sulphur Survey

No. 25. Industrialization in Sub-Saharan Africa: Strategies and Performance (also in French, 25F)

No. 26. Small Enterprise Development: Economic Issues from African Experience (also in French, 26F)

No. 27. Farming Systems in Africa: The Great Lakes Highlands of Zaire, Rwanda, and Burundi (also in French, 27F)

No. 28. Technical Assistance and Aid Agency Staff: Alternative Techniques for Greater Effectiveness

No. 29. Handpumps Testing and Development: Progress Report on Field and Laboratory Testing

No. 30. Recycling from Municipal Refuse: A State-of-the-Art Review and Annotated Bibliography

No. 31. Remanufacturing: The Experience of the United States and Implications for Developing Countries

No. 32. World Refinery Industry: Need for Restructuring

( ) Indicates number assigned after publication.

(List continues on the inside back cover.)

WORLD BANK TECHNICAL PAPER NUMBER 60

Community Piped Water Supply Systems in Developing Countries

A Planning Manual

Daniel A. Okun and Walter R. Ernst

The World Bank
Washington, D.C.

The International Bank for Reconstruction
and Development/THE WORLD BANK
1818 H Street, N.W.
Washington, D.C. 20433, U.S.A.

Manufactured in the United States of America
First printing April 1987

Daniel A. Okun is Kenan Professor of Environmental Engineering, Emeritus, in the Department of Environmental Sciences and Engineering of the School of Public Health at the University of North Carolina at Chapel Hill. Walter R. Ernst was an engineering research assistant in the department and is now a consulting engineer in Switzerland. Dr. Okun is also a consultant to the Urban and Water Supply Division of the East Asia and Pacific Projects Department of the World Bank.

Library of Congress Cataloging-in-Publication Data

Okun, Daniel Alexander.
Community piped water supply systems in developing countries.

(World Bank technical paper, ISSN 0253-7494 ; no. 60)
Bibliography: p.
1. Municipal water supply--Developing countries--Planning. 2. Waterworks--Developing countries--Planning. 3. Water-supply engineering--Developing countries. I. Ernst, Walter R., 1929- II. Title. III. Series.
HD4465.D44038 1987 363.6'1'091724 87-8161
ISBN 0-8213-0896-3

Abstract

This document, when supplemented by specific local data, provides officials in developing countries with a manual that can assist in the planning of community piped water supply systems. It is intended to be the basis for the preparation of country planning manuals; **Notes** throughout the document indicate where local input is required.

A checklist for planning and priorities for selection of projects precedes the elaboration of principles for planning. Principles include consideration of health, economic and social benefits; environmental and social constraints; and technical, economic, financial, logistic, institutional, and sociocultural considerations. The use of low-cost indigenous materials, simplicity for easy operation and maintenance, financial and institutional capacity, and community participation are emphasized.

Project preparation, including project identification, pre-feasibility studies, monitoring and evaluation and technical planning are described. Technical subjects include water quality, system capacity, selection and development of sources, pumps, transmission lines, distribution networks, and water treatment. Attention is given to operation and maintenance, economic and financial considerations, logistic support, and local institutions, including human resources development. In addition to reference materials, annexes include information useful to those who are responsible for preparing country manuals.

Table of Contents

Preface

The preparation of this document was stimulated by a World Bank rural community water supply project for the People's Republic of China. The senior author was asked by the Bank to help the Office of the Central Patriotic Health Campaign Committee, the agency responsible in China for International Drinking Water Supply and Sanitation Decade activities, to prepare a water supply planning manual for use in the villages, counties, and provinces of China.

After lengthy discussions with the technical staff of the Committee, a draft was agreed upon, and the manual was published in June 1984. Almost 40,000 copies have been distributed. Because the manual appeared to be a valuable instrument for water supply planners, Arthur Bruestle, of the Urban and Water Supply Division of the East Asia and Pacific Project Department of the World Bank, asked that the manual be revised for use in other developing countries. This manual is the product. It differs from the China manual in that the latter was directed towards only one country and thus included specifics on materials, specifications, and institutions.

This manual is designed to be adapted by water supply agencies in any country. Places are indicated in the text, under **"Note"**, where local information is to be inserted to make the manual locally useful. Adaptation of this manual to local conditions will require more or less effort depending upon the status of data collection in the country. Where institutions have been well established, data will be readily available. However, in many countries, the data will be limited in scope, and considerably more time will be required to supply the **"Note"** material. As experience and data are collected in a country, the manual should be revised.

Many countries already have excellent manuals, which are identified in the bibliography and which may be useful in adapting this manual to local needs.

We are grateful to many people who have helped with this document. Most particularly we should like to thank John Huang and Claudio Fernandez, colleagues of Mr. Bruestle at the World Bank, who were generous with their time.

Daniel A. Okun and Walter R. Ernst
University of North Carolina
at Chapel Hill

Chapter 1

Introduction

The World Health Organization (WHO) estimated, in 1980, that more than 1300 million people had no access to a safe and adequate water supply, and that more than 85 percent of these people live in rural areas in developing countries. Improvement of water supply service in rural areas in developing countries is a priority of the International Drinking Water Supply and Sanitation Decade, launched in 1981 by the United Nations family of agencies.

The World Bank has endorsed the International Decade and is supporting efforts in this sector. It has funded water and sanitation projects since 1961, investing more than $4000 million in these projects. The financial needs to achieve the goals of providing adequate water supply service to all urban and rural people are estimated to range from $100,000 million to $200,000 million, with per capita costs varying from $50 to $150. Efforts to provide adequate sanitation and protection of water sources are likely to require additional investments of similar magnitude. Considering these costs, as well as the resources at the disposal of the Bank and other financial assistance agencies, most developing countries will have to rely largely on their own financial initiatives and resources to meet the needs for water supply and sanitation.

In response to this situation, the Bank is engaging in activities to improve the capacity of governments and their institutions to take a role in achieving the Decade's goals and the targets set in their countries. The Bank also supports local officials and planners in their efforts to plan, design, construct, and operate and maintain, new water supply and sanitation facilities through assistance by staff members, consultants, workshops, training programs and counterpart training during project execution. In collaboration with United Nations agencies, the Bank also sponsors research activities in low-cost technologies, and special publications on technical and economic options, as well as the development of handbooks, manuals and computer software for planners and administrators. This manual is part of that effort.

1.1 Objectives of Manual

This manual is intended to provide officials and planners in developing countries with guidance in the appropriate planning of piped rural water supply systems for communities ranging from 500 to 50,000 people. It focuses on the planning for construction of technically and economically appropriate water supply systems.

Longterm Reliability, Viability, and Benefits

A large proportion of new rural water supply systems are not functioning properly; they show major deficiencies after short periods of operation and are often not fully utilized by the targeted population. Reasons include: inadequate design and construction, inadequate funds and personnel for operation and maintenance, and inadequate logistic support for spare parts, chemicals and fuels. The lack of user involvement and consultation with regard to levels of service and potential benefits often result in an unwillingness to pay for and maintain the service provided. (Chapter 2 contains more on benefits and constraints.)

Reduce per Capita Cost and Improve Maintenance

The per capita cost of water supply systems tends to increase significantly with decreasing village population, especially if the population is relatively dispersed, and the size of a village influences its ability to pay for and maintain a water supply system (Saunders and Warford, 1979). In some cases the ability to pay for water, thought to be about 5% of the average income of the users, would not even be sufficient to cover the cost of the pre-investment planning which includes the preparation of a master plan and a feasibility study (Leano, 1983).

Per capita planning costs increase at a greater rate than construction costs with decreasing size of the service population. In the first project stage in the Philippines the cost of the planning and feasibility studies amounted to an average of about 4% of the estimated construction cost for cities of about 200,000. For communities of about 40,000 this percentage increased almost tenfold to 38%.

Consideration of Local Conditions

A fully standardized approach to planning is too inflexible to respond to requirements for varying levels of service, resulting in low consumer satisfaction and willingness to pay (Lauria, 1983). Flexible design criteria which permit improved community participation are desirable.

Planning should, as far as possible, rely on local planners to minimize consultant costs. A planning approach should be developed which can be applied by local staff with relatively little training and planning experience. This should reduce costs and address local conditions.

1.2 The Approach

This manual provides information for local planners, and introduces them to considerations likely to be important. Because of the wide variation in local conditions, this manual can serve as a basis for preparation of country manuals which consider local constraints. Some sections will have to be adapted (and possibly supplemented) to fit the specific local needs of a particular project. Special **Note** statements are highlighted to draw attention to information which should be provided locally.

Chapter 2 provides information on the objectives and potential health, economic and social benefits of community water supply systems; and the physical (hardware) and non-physical (software) components important in the planning process. This chapter also provides a summary of the important steps in rural water supply planning. Chapter 3 is an overview of the project development process for the preparation of initial project identification and prefeasibility studies which usually incorporate a number of communities or systems in a region, and Chapter 4 is an overview of the preparations involved in planning individual water supply systems.

Chapter 5 addresses water quality, drinking water standards, treatment and monitoring of water quality and their impact on costs, health benefits and operations. Chapter 6 covers the required system capacity including the factors which can affect the level of service and consequent water demand and their impact on cost, operation, consumer satisfaction, and health and economic benefits.

Chapters 7 through 13 cover the technical components of water supply systems including water sources, wells and intakes, pumps, transmission, treatment, distribution and storage, and sanitation and drainage.

Chapter 14 examines planning for operation and maintenance. Chapter 15 elaborates on financial and economic considerations including the estimation of costs and the selection of least cost options. Chapter 16 addresses logistic planning and the need for standardization, quality control and the development of schedules. Chapter 17 examines the need for development of personnel to plan, design and construct, and operate and maintain, the systems. Lastly, Chapter 18 stresses the importance of institutional development, including regionalization, which has a large potential for economies and efficiencies of scale.

Additional supportive information is provided in several Annexes, together with a "Bibliography" with additional "References" to more detailed information, selected for their availability in developing countries; a "Project Data Sheet" (developed by WHO) which summarizes the information commonly required for project identification; and an "Introduction to the Use of Microcomputers" in rural water supply planning, which provides an overview of existing programs that may reduce planning time and costs.

This manual does not provide detailed information for design, construction, or operation and maintenance (O&M). These should be the subject of separate manuals. Nevertheless, references to design, construction, and operation and maintenance manuals are given in the Bibliography. Sanitation planning is included only to the extent it impacts on water supply planning.

1.3 Summary and Checklist for Water Supply Planning

Certain principles are applicable generally. This manual applies to piped systems providing water service through standposts, yard taps, and/or house connections. Water service does not include capacity for wide use of flush toilets or fire fighting. The following is a checklist that should be reviewed by local, regional or national agencies responsible for water supply projects. Any project that violates one or more of the following principles or that departs significantly from the values shown should have special justification.

(1) Before planning a new supply, the possibility of taking water from a nearby community or joining with other villages in a new supply should have been thoroughly explored.

(2) The potential of springs or wells should have been examined before settling on a surface source. The surface source selected should be the highest quality feasible.

(3) Local, low-cost materials should be used in preference to higher cost materials brought in from a distance. For example, plastic pipe should be selected over cast iron, concrete should be selected over steel, etc.

(4) Designs should be simple and permit easy operation and maintenance. Complicated prefabricated steel package plants, pressure filters, activated carbon filters, etc. are costly and difficult to operate and maintain.

(5) The design population should be about 25% greater than present population.

(6) Based on a design population of 3000, and 80 lcd on the maximum day, the design capacity of raw water pumps and treatment plant should be 240 m^3/day. A design capacity of 15 m^3/hr would be satisfactory as this would permit 16 hours operation. For other populations, the design capacity would be proportional. Capacities up to 25% greater would be acceptable without additional review.

(7) Storage of 20 to 30 m^3 per 1000 population should be available in the system in a clear well or in an elevated tank.

(8) If chlorination is required, a contact time of at least 30 minutes should be available. This can be in a clear well or in an elevated tank.

(9) If no elevated storage is available, high-lift pumps (including raw water pumps where no treatment is provided) and transmission mains should be about 10 to 15 m^3/hr capacity for 1000 population. This can be reduced to about 3 to 5 m^3/hr if elevated storage is available.

(10) If elevated ground is available near the village, elevated storage in a ground storage tank should be provided. If the land is level, an elevated water tower is desirable or standby power should be available to provide continuous water pressure. Elevated water towers should be at least 3 m and not more than 5 m above the tallest structure.

(11) Continuous water pressure and water service should be provided. If sufficient storage is available, the time of plant operation can be curtailed.

(12) The water supply must have a master meter to measure water produced for distribution.

(13) If water is scarce, or the cost will be high because of excessive pumping height, long transmission mains, or the need for complete treatment, metering of services is advisable. If householders are expected to use water for private enterprises, such as gardens or animals, metering should be considered.

(14) The water system must be affordable. In general this requires that:
- Construction cost be no more than ___ per capita.
- Operating costs should not exceed about ____ per m^3.
- Total recurrent costs, including debt service for no more than 10 years, should be less than about 3% of the average annual income of the village during the preceding year.

> **Note:** The local cost figures should be inserted in the blanks above.

1.4 Priorities for Selection of Projects

Funds and resources will seldom be available to initiate projects in all the communities that could want them, so a system of priorities is helpful in selecting projects. The following criteria are appropriate:

(1) Existing water supply is of poor quality. The use of waters high in fluorides, or dissolved minerals, or drawn from highly polluted sources should be discontinued as soon as possible.

(2) Existing water supply is inadequate. Where water needs to be carried long distances (1000 m) or to greater elevations (100 m), a new supply is warranted.

(3) The community evidences its desire to improve the supply.

(4) The community has adequate institutional and technical resources available to it.

(5) The community has adequate financial resources and demonstrates a willingness to pay for a new supply.

(6) The community has access to necessary material and human resources.

> **Note:** The country manual should tailor these priorities to its own situation. It might adopt a weighted point system for each factor so as to establish a ranking of communities.

Chapter 2

Principles and Basic Considerations

2.1 Objectives of Water Supply Projects

Adequate, accessible and safe water supply is a prerequisite for improved public health and socio-economic development. Improvements in water supply can result in a number of substantial benefits.

Health Benefits

Improved water supply contributes to reducing the mortality rate of children and to increasing life expectancy. Moreover, it reduces the suffering and hardship caused by water-related diseases, and results in significant benefits to individuals and to society. These benefits may include:

(a) Savings in medical treatment, including costs of medicines;

(b) Work days and income saved by the sick as well as by relatives responsible for their care;

(c) Savings in travel costs and time required to obtain health care; and

(d) Increased productivity and extended lifespan.

Economic Benefits

Improved water supply produces economic benefits:

(a) Reduces time required to collect and transport water. For example, a third of the total worktime of female heads of households in villages in Kenya was devoted to collecting water, while only 17% was spent in preparing food and 21% in economic activities, such as farming, herding or marketing (World Bank, 1980).

(b) Improves opportunities for keeping livestock or growing subsistence crops.

(c) Communities with adequate water supply attract small businesses, and may reduce outmigration.

(d) The development process for water supply may be extended to other community projects.

(e) In larger communities with buildings and other properties, water supply may be designed to provide improved fire fighting capacity.

Social Benefits

Easier access to safe water can improve family and social development. When women are freed from water bearing, they have more time not only for income-producing work, but also for child care and household tasks, as well as training and educational programs. Children obliged to carry water can instead spend their time in school.

2.2 Environmental and Social Constraints

The quantification of these benefits is complicated by local environmental, socio-economic and cultural factors (Saunders and Warford, 1976).

Health benefits are particularly difficult to quantify. Improved water supply is generally only a starting point towards improved public health. To gain the full potential health benefits of water projects, corollary inputs, such as nutrition, hygiene, and sanitation are necessary.

Planning a water supply intervention requires an understanding of the water-related diseases that are to be attacked. Table 2-1 lists the most important such diseases, classified according to their transmission route, and indicates the factors involved.

The first group, the fecal-oral diseases (often called water-borne diseases), are transmitted by contaminated water which is ingested. They can also be transmitted by any route which permits fecal material from sick persons to pass into the mouth of another person. Therefore, control of these diseases also depends on personal hygiene and sanitation.

The second group, called water-washed diseases, may be significantly reduced by improved personal hygiene, for which sufficient conveniently available water for personal use is essential.

The third group, water-based diseases, are caused by parasitic organisms which develop in water snails and can infect people who come in direct contact with water contaminated with such organisms. They might be prevented by improved sanitation, by the control of water snails and by keeping people away from contaminated water by the provision of a safe and adequate water supply.

> **Note:** The country manual should list those diseases that are significant in the country. Where prevalence of a disease varies from place to place, a map showing endemic areas would be useful.

The health benefits of a water supply project depend on a number of environmental and behavioral factors which should be considered in the planning process:

(a) Water quality, including source protection and water treatment (Chapter 5);

(b) Water quantity for personal hygiene, such as handwashing, bathing, and washing of food and dishes (Chapters 4 and 6);

(c) Accessibility to safe water (Chapter 4);

(d) Reliability of supply (Chapter 15);

(e) Adequate sanitation (Chapters 2 and 7);

(f) Health education programs to explain to the people served the benefits of improved water supply and motivate them to participate in the planning, operation and financing of the work, and to utilize the improved water supply for personal hygiene. Such efforts should be coordinated with local institutions.

Table 2-2 categorizes the relationships between water supply improvements and benefits that may be achieved.

2.3 Project Preparation and Management

A water supply project is often obliged to cooperate with other branches of government.

Integration and Coordination: Water supply projects may often be developed in concert with other sectors, such as housing programs, health clinics, or irrigated agriculture. This permits a larger project than might be manageable for water supply alone with a reduction in household costs because of economies of scale.

Table 2-1 Classification of Water-Related Infections, Including Preventive Strategies

Category	Infection	Pathogen[a]
1. Faecal-oral	Diarrhoeas and dysenteries	
	Amoebic dysentery	P
	Cholera	B
	E. coli diarrhoea	B
	Giardiasis	P
	Rotavirus diarrhoea	V
	Salmonellosis	B
	Shigellosis (bacillary dysentery)	B
	Enteric fevers	
	Typhoid	B
	Paratyphoid	B
	Poliomyelitis	V
	Hepatitis A	V
	Leptospirosis	S
	Ascariasis	H
	Trichuriasis	H
2. Water-washed		
(a) skin and eye infections	Infectious diseases	M
(b) other	Louse-borne typhus	R
	Louse-borne relapsing fever	S
3. Water-based	Schistosomiasis	H
	Guinea worm	H
4. Water-related insect vector		
(a) biting near water	Sleeping sickness	P
(b) breeding in water	Filariasis	H
	Malaria	P
	River blindness (onchocerciasis)	H
	Mosquito-borne viruses	
	Yellow fever	V
	Dengue	V

Transmission Mechanism	Preventive Strategy
Water-borne	- improve quality of drinking water - prevent casual use of other unimproved sources
Water-washed	- increase water quantity used - improve accessibility and reliability of supp... - improve hygiene
Water-based	- decrease need for contact with infected water - control snail populations - reduce contamination of surface waters by excr...
Water-related insect vector	- improve surface water management - destroy breeding sites of insects - decrease need to visit breeding sites

(a) B-Bacterium; R-Rickettsia; H-Helminth; P-Protozoa; S-Spirochete; V-Virus; M-Mi...

Source: Adapted from Cairncross et al. (1983)

Table 2-2 Relationships between Water Supply Improvements and Potential Benefits

Benefits	*Accessibility*	*Quantity*	*Quality*	*Reliability*
Time-saving	Saving on the water collection journey for each household	–	–	Saving during season when unreliable sources fail
Health improvement	Water piped into homes may increase quantity used (see next column) and reduce exposure to water-based disease	Potential improvement in hygiene if additional water is used	Precludes one avenue of faecal-oral disease transmission	May avoid seasonal use of more polluted sources of water
Labour	Labour released by time-saving, and indirectly by health improvement	Indirect through health improvement	Indirect through health improvement	Seasonal time-saving
Agricultural advance	Possible indirect benefit from labour release	Surplus or waste available for gardening	–	Seasonally significant in some cases
Economic diversity	A prerequisite, but not usually a major one	A prerequisite, but not usually a major one	–	Permits permanent settlement

Source: Feachem (1978)

Regionalization: It may be feasible to obtain water supply from a community nearby that already has a supply. Alternatively, if nearby communities also need water supply, a regional effort may reduce the unit costs (Chapter 18).

Financial Resources: The availability of local, national, or international funding is important in project preparation as lending agencies have their own criteria for project support. Lending agencies might have greater interest in a joint project such as with housing which would permit the water supply project to be funded more readily.

Institutional Capacity: The availability of personnel and organizations to undertake project preparation and then design, construction, operation and maintenance, and management, are important in planning.

Government Responsibility: Those who are responsible for initiating, executing, and approving all phases of the project, as well as the agency responsible for regulating performance, need to be identified early.

Legislation: The right to build a water project and to abstract water from underground or from a river may need to be established in legislation. Examination of all relevant laws and regulations is important.

Support of Inputs: A water supply project needs to draw upon other resources for project promotion, for establishing community understanding, for seeing to ancillary activities such as training and the provision of sanitation, and schemes for financing and charging for the water supply. Institutions need to be identified that can provide these supportive services or, if they are not available, steps must be taken to develop them.

Pilot Projects: If a large water supply program is to be undertaken with a large number of community systems to be developed, pilot projects to test the technology and the institutional arrangements may be useful. They may also be used for training personnel.

Evaluation: System evaluation of all activities conducted under the project needs to be institutionalized either within the water supply agency itself or with some other agency of government.

2.4 Technical Considerations

Most of the points to be incorporated in an evaluation of technical issues are discussed in detail elsewhere in this manual. However, some points need to be emphasized early:

Water Quality: Sources of water are often selected on the basis of earlier experience in the area. Accordingly, it is essential to ascertain whether or not present supplies are of satisfactory quality and, if not, whether the poor quality results from natural circumstances such as high mineralization of groundwater or from man-made pollution.

Selection of Source: A major principle in water supply planning is that waters should be drawn from the purest source that is feasible. This principle needs especially to be followed in developing countries where water-borne infectious disease may be endemic and the health risk is much greater than in industrialized countries. Groundwater is generally the best source.

Water Acceptability: A water may be safe but be unacceptable because of color, turbidity or odor or perhaps because it is different from what the community is accustomed to.

Quantity: The source should provide sufficient water during the highest demand days in dry periods, otherwise people will turn to other sources of uncertain quality. Quantity is as important as quality and may be more important where water-washed and water-based infections are prevalent.

System Capacity: The factors which establish the required capacity include the service area, the design period, the population at the end of the design period, the per capita average and peak water consumption, which is based upon the level of service selected, and the extent to which water is to be provided for animals, gardens or other home industry activities. In developing countries the cost of money is high and the availability of capital is limited so the period of design may be ten years or less.

System Layout: The layout of a system is affected by hydrologic and topographic conditions. Gravity systems are preferred if they can be developed at low cost. The choice between gravity flow and pumping, as well as most other technical choices, depends upon minimizing cost, including capital and operation and maintenance.

Distribution System Layout: Many options are available, with looped networks generally being preferable, although somewhat more costly than branched networks. Where residential metering is not to be provided, a layout which will allow district metering would be desirable.

Technology and Materials: Because labor costs tend to be low as compared with capital and equipment costs, designs should be labor intensive, minimizing importation of materials from abroad.

Metering: On the other hand, metering is useful where water conservation is important and where customers are to meet the costs of the supply. In small communities the cost of the meter may be a substantial part of the total cost and may not be warranted. Distribution of a product without regard to the amount used encourages a disrespect for the product and discourages conservation and collection of charges that are essential to the integrity of the system.

Sanitation: Where sanitation is to be provided, the system of sanitaion adopted influences the amount of water required. Where flush toilets or pour-flush latrines are to be provided, the water demand will be substantially greater than where water is not used for latrines. If water-carried sanitation is expected to be introduced later, provision can be made for enlarging the water supply system at that time.

2.5 <u>Economic and Financial Considerations</u>

Chapter 15 is devoted to their exploration in some detail. Key elements that need to be considered are:

Financial Feasibility: Financial resources for the project whether drawn from local, national, or international sources must be adequate to meet all the costs of the planning, design, construction, operation, and maintenance, together with normal expansion, of the system.

Willingness to Pay: If the population served is not willing to contribute to the project, it is not likely to succeed. At one time, water was expected to be delivered free. Now, at the very least, the population served is expected to meet operation and maintenance costs. However, this requires subsidies from some source for new systems and for expansion of existing systems. The preferred approach is that <u>all</u> of the costs, including capital (or replacement) cost, be met from charges to those being served. Subsidies should be in the form of loans which are expected to be repaid from reserves. Willingness to pay has been estimated at about 3 to 5% of family income, although this varies considerably depending upon economic circumstances.

Borrowing Rates: The interest rates for borrowing for water supply are an important determinant of the feasibility of a water supply project. In determining water charges, a decision needs to be made as to whether the interest paid, or the shadow rate, which is indicative of the true value of money, should be used.

Tariff structure: The system for charging needs to be established before the project is undertaken so that community and householder commitment is clearly understood. The charging scheme should be easy to understand, easy to operate, and be perceived as being fair.

Economies of Scale: Per capita costs tend to decrease as the population served increases. An increase of about 10% in capacity usually results in a cost increase of only about 4% (Lauria, 1982; Hebert, 1985). The economies of scale also exist in management where, in addition, efficiencies of scale result from the ability to employ more skilled personnel for larger works. Larger systems also can generally borrow money at lower cost.

2.6 Logistic and Institutional Considerations

Some organization must be in place in order for a project to get to the point where a manual such as this is useful. Some agency has a responsibility for providing water or at least providing technical assistance to communities that supply water. These institutions are often inadequately staffed both in numbers of personnel and in their qualifications. Significant increases in funds and technical assistance are being given directly by international agencies, and nongovernmental and voluntary organizations that provide direct service as well as loans and grants for country agencies that implement projects.

> **Note:** The institutions responsible for overall project development and/or management need to be clearly identified here and their range of activities fully described in Chapter 18.

Institutional Assessment: If the lead institution has not had experience in the rural community water supply field, measures need to be taken to identify and acquire suitable staff. Experienced personnel will need to be employed if the time required for training of personnel is too great to permit timely employment for initial projects.

Human Resources Assessment and Development: With the onset of the program, the numbers of personnel and the skills required can be expected to increase sharply and to remain at a level not generally met by the educational and training programs of the country, so that a human resources development program needs to be established and maintained continuously.

Logistic Support: The timely procurement, distribution, and storage of materials and equipment for planning, design, construction and operation of the projects need to be assured through sound organization.

Standardization: To facilitate and reduce the cost of materials of construction and equipment, the number of different types and sizes of units should be limited, for which standardization is necessary. In the absence of any national standards agency, a water authority may undertake this responsibility for its own sector.

2.7 Sociocultural Considerations

The willingness to pay for and participate in the construction and maintenance of a water system depends upon a continuing program of community education, and community involvement in establishment of policy. Contributions of labor by villagers may reduce the cost of a project, and participation in the project helps assure continued concern for the project. However, the organization of villagers may be so troublesome that contracting of construction proves more satisfactory.

Chapter 3

Project Preparation

This chapter provides guidelines for the staging of project development. The approach is based on the development process promoted by the World Bank, UNDP and other international agencies providing financial assistance for water supply projects in developing countries (Grover 1983). A manual cannot anticipate all problems or special circumstances associated with projects. It can serve as a guide. Potential financing agencies should be consulted early to determine the degree of preparation required for a specific project. Many development agencies provide loans, grants and expertise to assist in the preparation of projects prior to actual consideration of funding for implementation.

3.1 Stages of Project Preparation

Project preparation is a process in which planners must decide whether a proposed project and its goals can be achieved with the available resources, or whether additional resources are required. Resources include water resources, construction materials, equipment, chemicals, land, capital funds, and human resources (required personnel). Additional inputs or so-called supportive or softwater components include community involvement and education, training, strengthening of institutions and related activities.

The planner must evaluate the impact of local conditions and constraints on the project: size of communities, potential service area, population and population density, prevalence of water-related diseases, expected water demand, and available water resources. Locally encountered constraints may include: limited understanding of benefits of improved water supply, low ability or willingness to pay, social and cultural behavior, and inadequate institutional capacity to implement and operate new systems.

The Project Cycle

Planning involves a sequence of activities, some of which may be omitted or combined in smaller projects. The project planning cycle usually includes the following steps:

(i) Preliminary Planning includes the identification of the project and a pre-feasibility and/or a feasibility study, which help establish whether the project can be executed and operated successfully with the available resources;

(ii) Appraisal of the project by the appropriate regulatory or financing agencies uses the results of the pre-investment planning and arranges for the necessary approval and funds;

(iii) Negotiations secure the necessary approval and/or financing and other inputs (manpower, training, etc.) to execute the project;

(iv) Implementation includes the detailed planning, design, construction and commissioning of facilities, the training of the required staff, and, where they do not already exist, the establishment of the institutions required to support these activities;

(v) Operation and Maintenance of the new systems; and

(vi) Monitoring and Evaluation of the performance of the project, its utilization, and its impact.

Planning

This manual focuses on planning and appraisal. Elements of other steps are included only to the extent that they are important during the planning and appraisal steps. For implementation of the project, manuals for design, construction, and operation and maintenance are helpful. Examples of such manuals are listed in the bibliography.

Planning for small projects, which involve only one or two small towns or villages and which do not require significant institutional and logistic support on a national or regional level, is normally limited to a brief feasibility study.

However, rural community water supply projects often involve a number of individual sub-projects. In some cases, these sub-projects are handled by a single national or regional agency as a "package"; they are often referred to as sector programs. Such sector programs are commonly supported by the government and one or more external funding agencies.

Planning for sector programs or large projects involving a large number of different communities is normally carried out in two phases: Phase I to evaluate the feasibility of a project or sector program as a whole; and Phase II to evaluate the feasibility of the individual sub-projects after the project as a whole has been approved.

Phase I: The goal of Phase I is to assess the resources and supporting project components which are required to carry out the entire program. Project Identification should (i) identify the needs and objectives of the project (improved health, time and energy saving, and other social and economic improvements), and the area or communities to be served, (ii) provide a preliminary estimate of the necessary project components and inputs (physical facilities and supporting activities such as promotion, training and institution building), and (iii) propose further actions to be taken to proceed with the project planning. The Pre-feasibility Study should (i) evaluate the feasible technical and institutional alternatives, (ii) assess the implications of water-related diseases, economic conditions, and social and behavioral factors, and (iii) ensure the project is consistent with the sector plan.

Phase II: Its goal is to identify and develop individual sub-projects and evaluate their feasibility. Phase II may also include one or more pilot projects to test the planned implementation approach and the proposed planning criteria, technical solutions, and levels of service. Monitoring and evaluation of these pilot projects may provide feed-back and reveal difficulties and problems.

3.2 Organizational Arrangements

Project preparation requires inputs from individuals with knowledge and experience in many fields:
- demography, to estimate the expected population;
- surveying, to prepare the required maps and profiles;
- hydrology and hydrogeology, to evaluate the yield of available water resources;

- sanitary engineering, to evaluate the quality of the water sources, select an appropriate treatment technology, lay out the distribution system, and estimate the costs;
- economics, to consider factors such as discount rate and hidden costs in the evaluation of alternatives;
- institutional and human resource development;
- human behavior and communication, to stimulate community participation and anticipate problems; and
- public health, to provide for supporting programs such as sanitation and health education.

Central and local governmental agencies involved in water resources, public health, community development, finance, and other relevant fields should be contacted to secure necessary collaboration and reduce the need for such specialized expertise to be employed directly on the project. The planning of the interaction among specialists and agencies and the flow of information and ideas between all parties involved is an essential part of project preparation.

The steps to be followed include:

- acquire relevant information from related agencies, and through conducting field surveys;
- carry out necessary evaluations and prepare reports;
- determine the required inputs, and identify resources (such as required experts, supporting manpower, equipment, funds and time needed) for all required activities (such as evaluation of health or demand data, surveying, groundwater investigations);
- prepare organization charts which show collaborating agencies, senior officials and specialists involved and their function;
- prepare terms of reference which specify the tasks and responsibilities of each agency, official or specialist;
- prepare time and manpower schedules which specify the timeframe for each task (surveys, evaluation of technical alternatives, report preparation, etc.), and indicate the required manpower in man-months or man-weeks of various agencies, planners or specialists to carry out each task;
- estimate costs of the required services, equipment and office facilities (where not provided without charge by existing agencies), and prepare a financial schedule indicating the required funding over the planned project stage; and
- develop a control and monitoring system for checking the progress of the various tasks and the available finances.

3.3 Project Identification

Preliminary planning is usually initiated by a brief project identification report, which is based on existing information. For small projects this report may provide sufficient information for project approval. The major goals of this report are to draw the attention of the government and other possible funding agencies to the need and priority of the proposed project or program, and to obtain the necessary authorization and funding to carry out investigations for the pre-feasibility study.

In order to meet these goals the report should:

- provide data which support the need and priority of the proposed project, such as existing relevant studies, data on inadequate existing facilities,

and the incidence of water-related diseases and expected health and economic benefits;
- provide a map showing the project area and indicate the communities to be served by the project;
- show the number of people to be served, levels of service and expected economic and health benefits from the project;
- explain how the project fits into national or regional strategies and sector plans where such plans exist and is or should be supported by other sector related projects such as sanitation and health education, agricultural or rural development projects, etc.
- describe the present water sources and water supply facilities;
- outline proposed project components including physical facilities ("hardware") and supportive activities ("software") such as promotion, training and institution building;
- identify local social conditions and cultural behavior which may constrain project implementation, system utilization and realization of benefits of the project;
- provide: (i) a first rough estimate of the required material, equipment, supportive facilities, manpower and institutions to plan, implement, operate and maintain the planned facilities, (ii) a tentative schedule for implementation of the project, and (iii) a preliminary estimate of planning, implementation, and operation and maintenance costs and to what extent these costs can be recoverable;
- indicate further actions to be taken, and possible prospects for financial and planning support by regional, national and external agencies; and
- outline institutional responsibilities, the required expertise and supportive personnel, equipment, materials and time to carry out the pre-feasibility study, including a draft of the terms of reference for the preparation of the report.

A possible report format is provided in "Project Data Sheet" developed by the World Health Organization presented in Annex 2.

3.4 Pre-feasibility Study

This study is usually the second step in pre-investment planning. The goal of a pre-feasibility study for a small water supply project, which may involve a number of small sub-projects, should be to evaluate the best possible mix of project components (technical options and supportive "software" options) by considering the local physical, social, economic and behavioral conditions and constraints in the whole project area. It should:
- evaluate the technical and institutional alternatives (type of water source, treatment facilities, level of service, local or regional management, etc.);
- evaluate the implications of local health, economic, social, behavioral and legal factors on the design of the project;
- consider possible impacts of the project on wastewater disposal, sanitation and water resource protection;
- evaluate the required supporting "software" components such as community participation, health education, and human resource development; and
- ensure that the project is consistent with the sector plan and local or regional development strategy.

The specifics of the report should include the following:
- topography, hydrogeology, economic, and social factors;
- assessment of existing facilities;

- preliminary evaluation of technical alternatives, such as types of wells, treatment and storage facilities, pipe lines and material requirements;
- evaluation of existing and required standards for materials, equipment, design, and construction, as well as local capacity to produce products meeting the required standards;
- evaluation of role of community in design, construction and operation;
- preliminary design criteria such as water quality, level of service, demand per capita, peak factors, etc.;
- preliminary time schedules for planning and implementation;
- evaluation of institutional alternatives to plan, implement, and operate and maintain the project;
- assessment of required human resource development efforts to support the necessary institutional development;
- assessment of logistic support (supply of material, spare-parts, chemicals and fuels) for the construction, and operation and maintenance of the planned facilities; and
- evaluation of required support by internal and external consultants and specialists for planning, implementation and training.

3.5 Other Considerations

Informal contacts can be a source of information and can provide insight into existing local conditions and constraints. Members of the planning team should try to:
- familiarize themselves with programs of government and external development agencies operating in the sector;
- visit field offices and current projects in the sector in order to assess: (i) the level of local need for water; (ii) local government commitments; (iii) investments and inputs in sector projects, and related problems (such as delays, deficiencies in design, construction, material, operation and maintenance, etc.); and (iv) local sector organization including public and private institutions.

The project should be integrated into (or at least coordinated with) efforts in other sectors (including education, housing, agriculture, irrigation, transportation, energy supply, etc.). Such information may be obtained by consulting existing regional and sector plans which set goals based on estimated economic growth and outline efforts in various development sectors, including water and sanitation.

A Water Supply Sector Plan (or a combined water supply and sanitation sector plan) is a useful basis for project identification and pre-feasibility studies. If such a plan does not exist it may be developed as a part of one of these studies. A sector plan helps to coordinate separate water supply projects. The objectives of a sector plan are to:

(i) specify national and regional goals, objectives and time-frames or providing different regions with safe and adequate water supply;

(ii) identify and project the required financial, institutional and human resources, required to achieve these objectives;

(iii) set national standards, and national or regional criteria for project selection, planning and design, etc.; and

(iv) develop a sector strategy and goals for annual investment, training and education activities, and institutional development.

The World Bank and the World Health Organization Cooperative Program has published a case study of a sector plan for water supply and sanitation for the imaginary "Republic of Terrania." (World Bank/WHO, 1980). This publication may be obtained from both organizations.

Institutional and human resource development require substantial time and financial investments. If these are not sufficient, consideration might be given to reducing the size of the project or carrying it out in several smaller stages, employing external personnel. If expatriate consultants are involved, as is common in externally funded projects, the development of local expertise should be an important goal of the project.

3.6 Monitoring and Evaluation

Monitoring and evaluation are systematic ways of learning from experience. They are a management tool which increases the effectiveness of programs.

Experience with rural community water supply in developing countries is poorly recorded and disseminated, so that little is known about the factors which lead to success or failure. The importance of evaluation in obtaining such information and feed-back increases as the financial commitments and risks grow. The International Reference Center for Community Water Supply (IRCWS) recommends allocating at least 1 to 2 percent of the capital budget to project monitoring and evaluation (Cairncross et al., 1980).

Types of Evaluation Studies

The evaluation of an existing community water supply project involves desk and field studies.

Desk studies are based on documents which provide information on:

- local costs and required personnel for planning, construction, and operation and maintenance of various system components;
- financial data such as discount rates, inflation, tax data, etc.;
- the required time to plan and implement components of the project; and
- common problems encountered at various stages of the project such as lack of accurate data, delays, materials losses, etc. The study may be enhanced by interviews with staff involved in the projects.

Field studies are important in assessing:

- functioning of the systems;
- utilization of the facilities, such as the percent of the community utilizing the improved system and to what degree the facilities are adequate to obtain the expected benefits;
- water quality, including source protection, treatment, distribution and household utilization;
- user participation, including satisfaction with the services, willingness to pay, willingness to participate in the planning, implementation of and operation and maintenance of the project, and understanding of the benefits of improved water supply); and
- economic social and health impacts and benefits, including the distribution of these benefits.

Monitoring programs for new projects improve evaluation and provide continuous feedback. Planning for gathering such information during project implementation should be part of the project preparation process. Procurement documents, material control lists, and progress and work reports and operating data may be used for monitoring.

Recommended Approach

In a first stage the study should:

- establish whether facilities are functioning properly and are fully utilized;
- identify the factors which influence proper functioning and utilization; and
- indicate possible actions to solve or reduce problems, such as changes in design, construction, use of materials, improved organization of operation and maintenance, user education, etc.; and by whom such actions should be taken.

Project impact and benefit evaluation become only meaningful in a second stage, after some time, and it has been established that facilities are functioning and utilized on a continuing basis. Attempts should be made to assess reasons for success or failure. Impact and benefit evaluations are relatively expensive because they require intensive field investigations. Considerable experience in public health, epidemiology and statistics are required and meaningful results are difficult to obtain.

WHO has published a "Minimum Evaluation Procedure" (WHO, 1983/1) which focuses on the functioning and utilization of water project facilities, and provides guidelines on how to plan the evaluation, collect and evaluate data and report the results. Its approach is based on the following indicators:

- Water quantity (is sufficient water provided even during high demand and dry periods?);
- Water quality (is the quality adequate at the source and at the point of use; are there problems with its taste or odor?);
- Reliability of the water supply (frequency and duration of interruptions in the supply and cause for such problems); and
- Convenience of supply (level of service, distance from households, use of unsafe sources and low quantities because of inconvenience).

A pilot project may be carried out as part of the pre-feasibility study to evaluate the success of various technologies and/or supportive components, the project as a whole is approved, to test and evaluate elements of the project.

Pilot projects are useful when no similar projects exist locally, to help in the development of manuals and the early initiation of training of personnel.

Chapter 4

Development of Individual Water Supply Projects

This chapter provides an overview of the considerations involved in developing a community water supply program or project.

4.1 Planning Preparation for Individual Project Development

The development of a planning manual adapted to the country or region to be served, and which considers the special constraints and the local conditions in the project area, is desirable. This manual, supplemented by local information as called for in the "**Note**" inserts can be the local manual. Some sections may have to be adapted to fit the specific conditions of the country or region to be served. During the adaptation process the following local factors should be considered:

- the range of size and type of the communities considered by the project;
- local economic conditions and the levels of service likely to be affordable (standposts, yard or house connections);
- local topographical, meteorological, and hydrologic conditions prevailing in the project area;
- local planning constraints, such as community involvement in planning decisions, legal and institutional requirements, etc.;
- local planning criteria such as water quality, supply per capita, maximum carrying distance from standposts, peak capacity factors, minimal system pressure, etc.;
- local planning standards such as standardized pipe sizes, fittings, pump types and sizes, well screens, and standard designs for wells, treatment and storage facilities;
- local supporting infrastructure and available energy sources such as reliability of electricity and fuel supply and/or potential of other power sources such as wind or sun; and
- capacity of local manufacturers and distributors to provide equipment such as pipes, pumps, and water meters.

Publications which may be helpful in considering additional technical or institutional options and adapting the manual are listed in the bibliography. Additional information and support may also be obtained from organizations involved in the water supply sector in developing countries, listed in Annex 1.

The materials and facilities usually required include: surveying equipment; equipment for groundwater investigations; meteorological, hydrological and hydraulic equipment; office, laboratory, workshop and storage facilities; office equipment; water quality test equipment if not available elsewhere in the area; and vehicles for transport of personnel and equipment.

More detailed information on logistic planning is in Chapter 16.

4.2 Technical Planning Considerations

A piped water supply system is composed of the following major components:

- water source and intakes (such as springs, wells, impoundments, or surface water intakes);

- raw water pumps where gravity flow is not possible;
- water transmission lines;
- treatment facilities;
- storage facilities (ground or elevated tanks); and
- distribution network, including pumps where necessary, and service connections.

Selection of these components depends on the available water sources and their quality, topographical conditions, system size, level of service, required capacity, and service reliability. The source is usually most critical as its selection influences the treatment required and the design of transmission facilities.

Figure 4-1 illustrates commonly used water supply systems showing major components and their arrangement, elements of which are discussed in subsequent chapters.

Period of Design

The target year for the design population and the area to be served need to be selected first. Unless other factors are involved, projects should be designed to be adequate for about 10 years after initiation of planning, or for a population 25% greater than present population. Chapter 6 discusses some of the factors that affect the period of design beyond this figure.

Level of Service

Where water is easily developed for individual houses and where houses are at a considerable distance from one another, on-site systems such as individual wells fitted with hand pumps or roof rainwater catchments may be most appropriate. Other manuals are available to serve as guidelines for such systems. (See Bibliography, "Wells and Handpumps")

In communities where on-site systems are not feasible and where funds for a piped system are not yet available, consideration should be given to distribution of water by vending. In general, the cost of water service from vendors is greater and the quality of water and service poorer than on-site or piped systems but they are more easily and quickly provided where funds for piped systems or extensive on-site systems will not be available for some years. A vending system should draw its water from a proper source, either a satisfactory well or spring, or from a nearby community with a water system. The water can be carried on any of a number of types of vehicles: walking tractors, bicycles, hand-carts, trucks, etc. The containers should be of good quality and be protective of the water. Routes for delivery can be designed to minimize the distance travelled. The best prospects for a satisfactory system will result where the community operates the system or at least regulates the system and assures that all homes along any given route are served.

Piped systems, whether to provide public hydrants (standposts), yard taps, or in-house connections, and the service area and population to be served in design year need to be decided. Consideration should be given to arriving at requirements for the design year by staging either the level of service or the service area. A piped supply with public standpipes can be provided initially and house connections added at a later date. If the design service area and population are to be much larger than at present, the system can be constructed in stages. Those elements that are costly to enlarge, such as

Figure 4-1 Water System Flow Charts

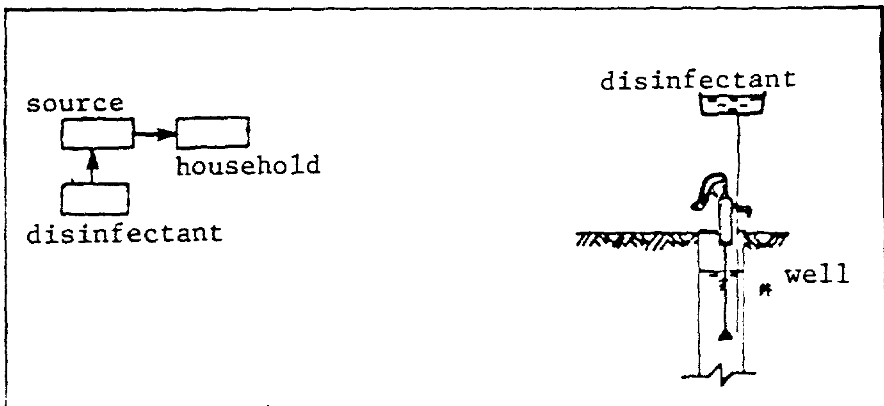
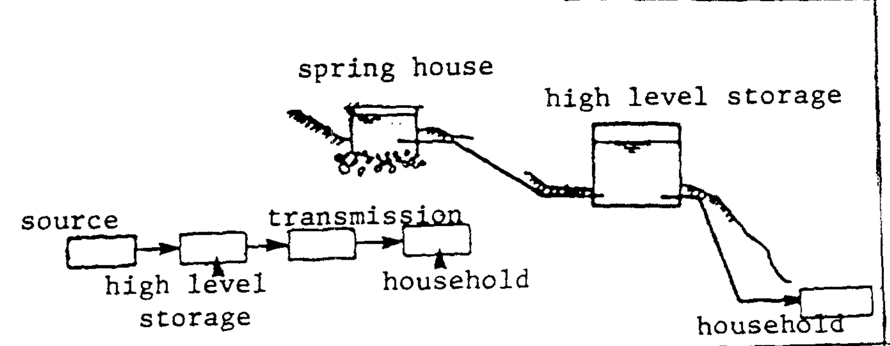
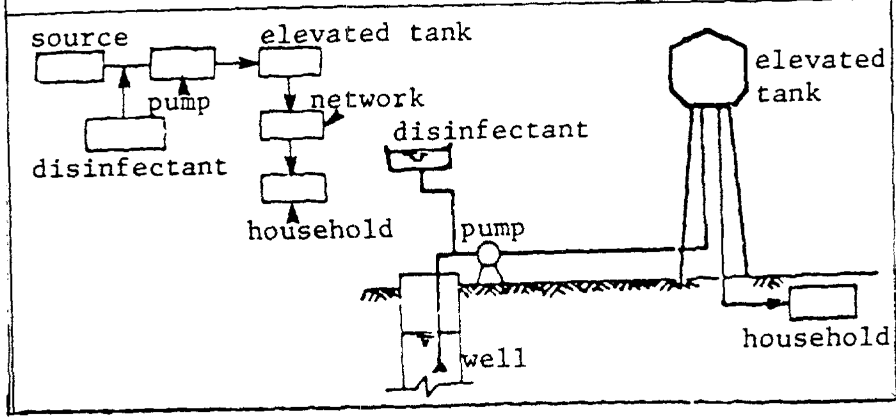
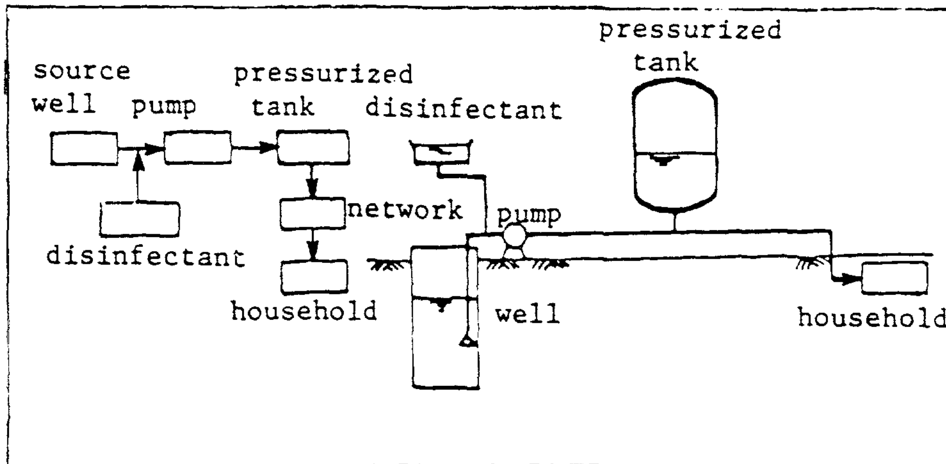
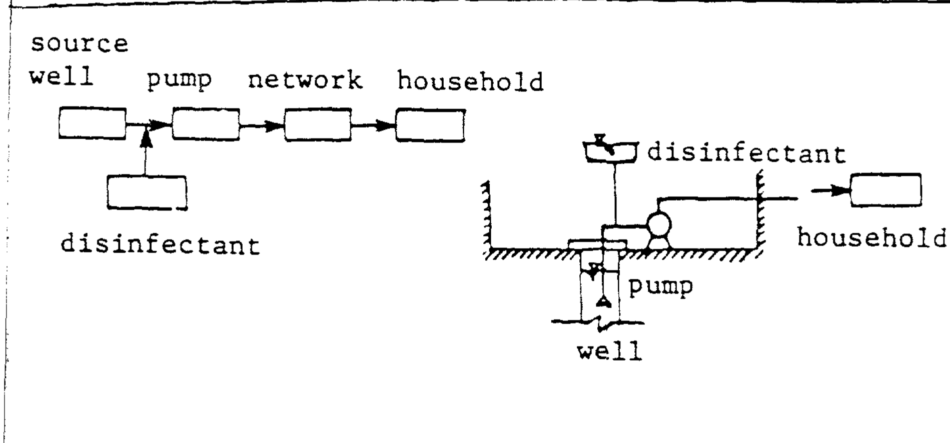
<table>
<tr><th></th><th>Applicable conditions</th></tr>
<tr><td>
</td><td>Shallow groundwater source, households are widely separated.</td></tr>
<tr><td>
</td><td>spring or mountain creek source, employing terrain to build high level storage</td></tr>
<tr><td>
</td><td>groundwater source, area level</td></tr>
</table>

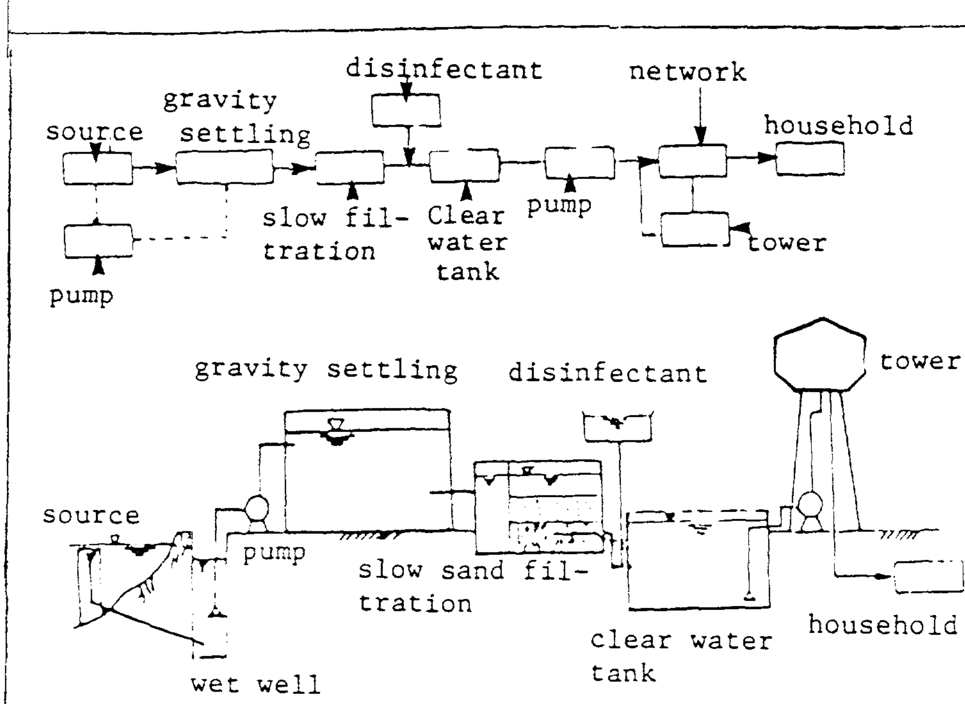
Figure 4-1 (continued) — Applicable condition



groundwater source, level area, chlorine contact may be inadequate



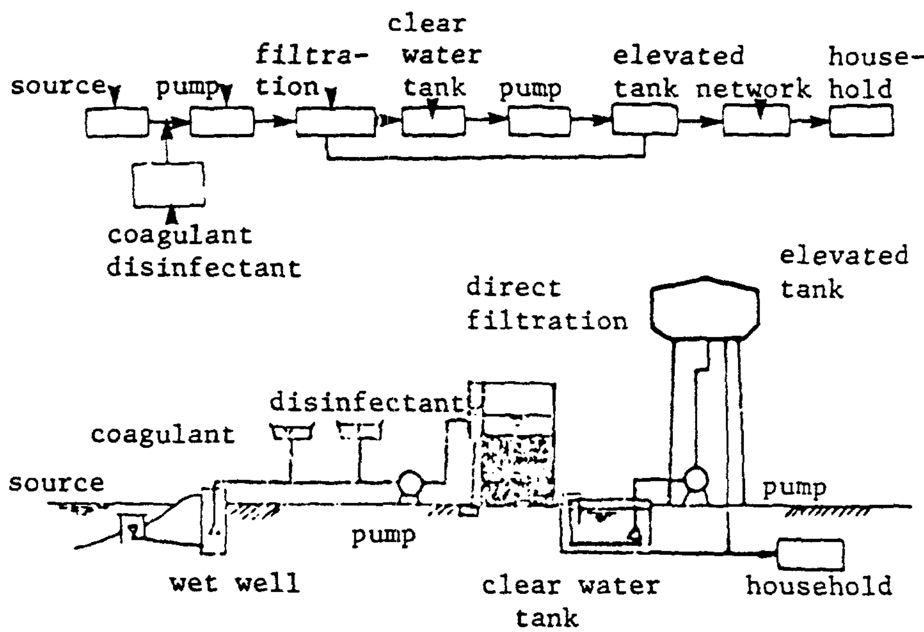
groundwater, small systems



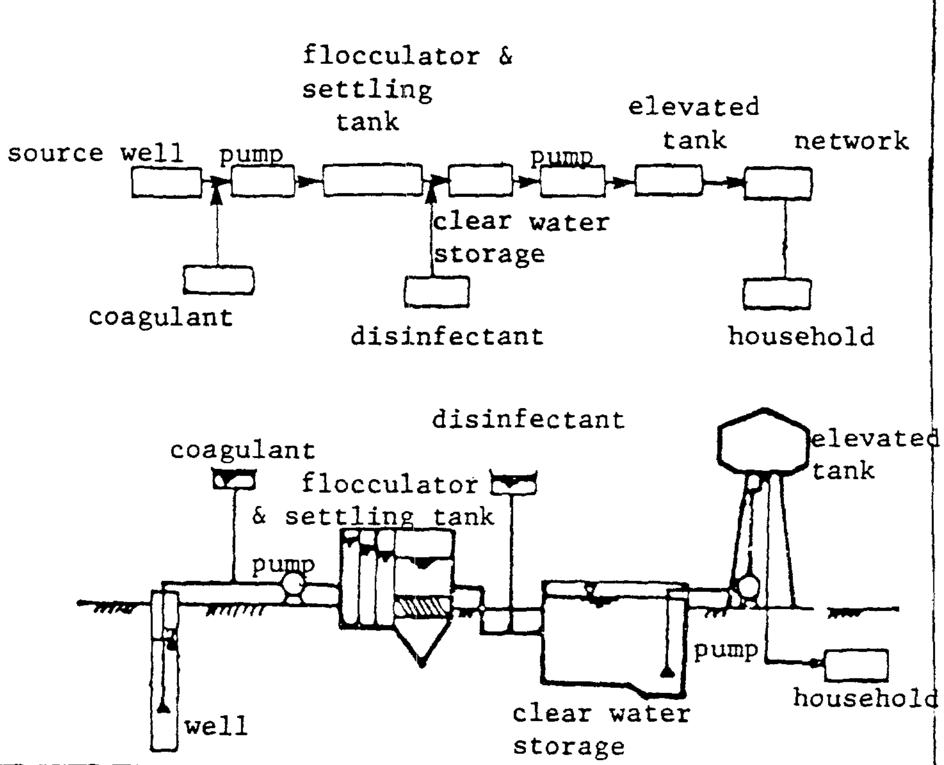
surface water. low turbidity, slow sand filtration

Figure 4-1 (continued)

Applicable conditions

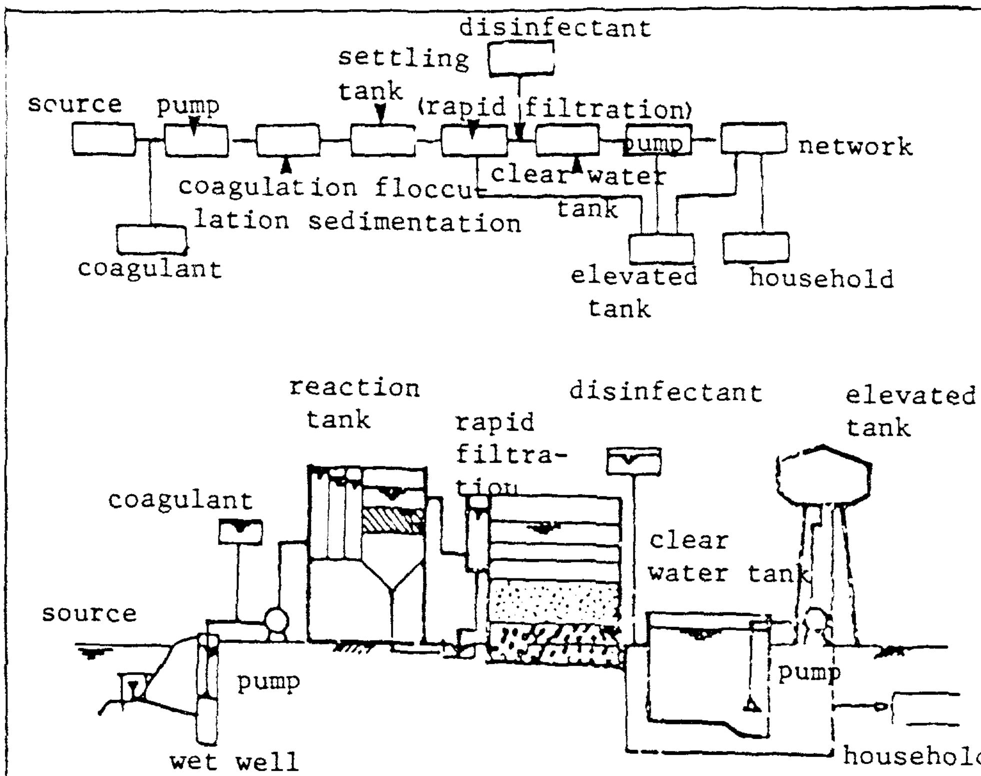
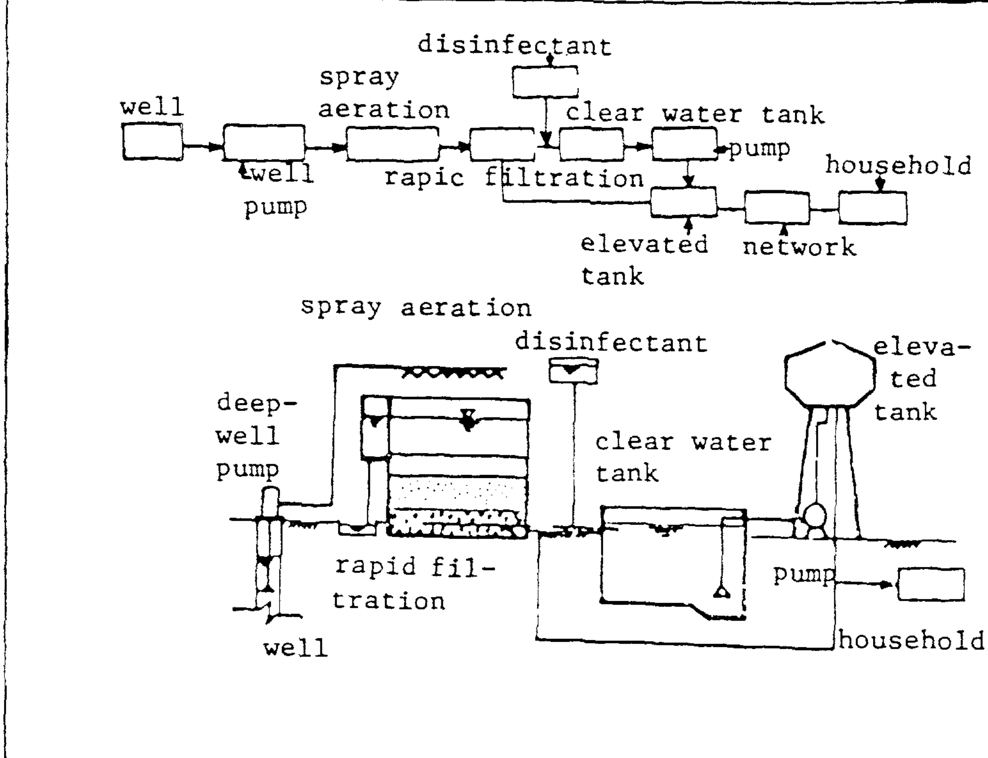


surface water source, the turbidity of raw water is low



groundwater source requiring treatment

Figure 4-1 (continued)

	Applicable conditions
	Surface water source, medium turbidity, requiring coagulation and filtration
	groundwater source, raw water contain iron

Source: People's Republic of China (1984)

dams, intakes, pumping stations, and possibly long transmission mains would be designed for the ultimate level of service and target year population, while the units of the treatment plant, pumps and pipes in the distribution system can be added as necessary. If the transmission main is long, a decision as to whether the ultimate capacity or an interim capacity should be provided can be determined by optimization procedures.

Capacity of the System

Based upon the estimated per capita consumption and the design population, plus the demand for institutions, commercial establishments, factories and irrigation, the design average demand can be calculated. Based upon the considerations discussed in Chapter 6, the design year, average demand, maximum-day demand, and peak or maximum hour demand should be calculated. Prior to determining the peak demand, a decision needs to be made whether the system is to provide for fire-fighting. The capacity of most of the system is based on the maximum day demand. Only the distribution system, including service reservoirs, is designed for the peak demand, which includes fire protection where this is to be provided. If an impounding reservoir is required on a stream, its capacity is based on the ultimate average demand.

Selection of the Source

The source needs to be able to provide water at the design maximum-day rate. If stream flow is inadequate in dry weather, an impoundment will need to be provided which will store runoff during the wet season to be used during the dry season. For any given yield, the size of impoundments increases as the ratio of the demand to the mean annual flow increases and as the flow variability increases. The detailed calculations for determining the size of an impoundment on a stream are beyond the scope of this manual. For planning purposes, about 6 months supply is required in humid areas, plus an allowance for silting, for evaporation and for a conservation pool for fish. In arid areas, the capacity for the same yield may need to be several-fold greater. In unusually dry years conservation measures and restricted service may be necessary to prevent exhaustion of the reservoir.

The minimum flow in unimpounded streams and the yield of wells in dry weather should be adequate to meet the maximum-day demand. If it is found that the yield in an occasional year was lower than the maximum day demand, the source may still be suitable; emergency conservation measures can be instituted during such dry periods. In general, the source should have been adequate on the average for 9 out of 10 years.

In some instances, the conjunctive or integrated use of ground and surface water is desirable. Surface waters would be drawn upon during wet weather while aquifers are being recharged. During dry weather, when streams are low, water would be drawn from wells. In such instances, natural underground storage replaces surface impoundments.

As noted in Chapter 7, many factors need to be considered in selecting a source:

- capacity;
- reliability;
- water quality;
- distance from community;
- elevation; and
- cost of development and operation.

The highest quality source that is economically and technically feasible should be selected; otherwise the choice is based on cost considerations, including cost of construction of intake, pump and transmission mains, and treatment plant, and the cost of operation and maintenance including power, chemicals, and personnel for monitoring, operation and repair of facilities. Some sources will have high construction cost but low operating cost, such as spring systems at high elevation some distance from the community that require no pumping and little treatment, while other systems may require less construction cost but extensive treatment and pumping. Selection in such cases is based on optimization calculations described in Annex 5.

When the source is selected, an investigation into water rights may be required. In some instances, permits for abstraction may need to be obtained.

> **Note:** Local regulations concerning abstractions, permits, etc. should be inserted here.

Intake, Raw Water Pumping, and Transmission

The design of intakes and wells (Chapter 8), pumping facilities (Chapter 9) and transmission mains (Chapter 10) need to be considered together. Some intakes require pumps with a suction lift, while others permit the pumps to be installed with positive suction. Smaller diameter transmission mains require larger pumps and more power, while larger diameter transmission mains permit smaller pumps and require less power. The optimization procedures described in Annex 5 are useful in the design of pumping and transmission main facilities. In general, such procedures indicate that a pipeline velocity of about 1 m/sec is optimum. Where construction is subsidized and energy is scarce and expensive, optimum velocities may be much lower, say 0.5 m/sec.

Treatment (Chapter 12)

Treatment plant design requires an understanding of chemistry and bacteriology in addition to civil engineering. The selection of treatment processes and the design of individual units require specialized input which can come from personnel at the local, provincial or national levels.

Standardization of design and construction is desirable to reduce the time for design and construction, and to reduce the number and types of materials required so that procurement can be facilitated (see Chapter 14). The philosophy in the design of rural systems is that facilities should be simple and rugged, with a minimum of mechanization, so that construction, operation, maintenance, and repair can be done with local personnel and local materials.

Distribution Systems

While the level of service selected affects the size of all elements of a system, the design of the distribution system is most affected. Chapter 11 presents the options for design and construction.

Maintaining minimum pressure continuously, 24 hours per day, should be the goal. Intermittent service does not save water. Failure to maintain water pressure in the system often leads to contamination from back-siphonage and infiltration into the system from underground. Instances where water leaving the treatment plant is of high quality but water delivered at the tap is contaminated are only too common in developing countries.

The distribution system must be capable of delivering the peak demand, which generally occurs at some time during the season of maximum day demand. Important to meeting this demand is the provision of elevated storage to provide for diurnal variations in demand and for emergency. Such service storage also permits the pumping station to be operated on shifts without loss of pressure.

Distribution system piping, fittings, and appurtenances should be standardized to assure their availability during construction. Elevated storage tanks can be prefabricated or built in place; standardized designs are helpful.

Logistic Planning Considerations

While a separate construction manual should be available, planning should assure that materials and equipment be listed, procured, and stored so that they will be available when needed. Materials and equipment must be selected to perform the service for which they are intended for the life of the project. Accordingly, national or provincial standard specifications for these materials should be used when available; otherwise, specifications need to be prepared. Finally, provision must be made to inspect and test the materials and equipment to assure that they meet the specifications (see chapter 16).

The organization that constructs the system is often different from the organization that is responsible for design. Accordingly, arrangements need to be made for inspecting the construction work as it proceeds to be certain that it proceeds according to design. This may be done by a qualified member of the water service organization or by a representative of the design organization.

Personnel Requirements

Qualified personnel for all phases of the rural water supply project are in short supply, so that their recruitment, training and employment needs to be considered early in the planning phase of the project. The lead time for acquiring and preparing personnel may well be greater than the lead time for any other part of the project.

Qualified engineers, knowledgeable in the quality and quantity aspects of community water supply, are required at provincial and perhaps local level to prepare the specific guidelines for local projects and to review plans for projects that are prepared by engineering technicians. At least one engineering technician, specially trained and experienced in water supply, should be available to be assigned to each project during its planning phase.

The superintendent of the construction project should be qualified in the construction of water supply systems. The numbers of other personnel of the diverse skills required, and the time required of each, depends on the size of the project, its complexity and the speed with which it is to be constructed.

Plans for obtaining operating personnel should be initiated during the planning phase. It is often desirable to have some of the construction personnel remain to operate the system or to have an individual recruited for operation be involved in the construction program. Most water systems require the services of a manager, an accountant, a laboratory technician, a maintenance person, operators, meter readers, and pipe crews. In a simple small rural system, these functions are combined in a small number of individuals, particularly if some of these functions can be performed by the local community in connection with its other activities. A larger system with commercial or industrial customers and a treatment plant may require separate individuals to provide each of these functions (see chapters 17 and 18).

System Start-up

The agency responsible for the design of the system should be responsible for initiating operation for a period of at least 30 days, to assure proper functioning, before turning the system over to the community. The agency should also be responsible for training the personnel and preparing an operating manual for the owner of the system which should provide the basis for the training.

Chapter 5

Water Quality

Countries have established drinking water standards to protect against the spread of disease through water. These standards generally consist of two parts: the first calls for the selection and protection of the source and the second prescribes limits for many of the contaminants found in water. Most attention is given to that portion of the standards that deals with the numerical limits for the contaminants as these are perceived as being easier to regulate. The general conception is that if the concentration of any given contaminant is below the limit set in the standards, the water is safe, but that if it exceeds this value it is unsafe. For most contaminants, there is no such threshold below which there is no harm. For many of the heavy metals, such as lead, and for the synthetic organic chemicals, any concentration has a deleterious impact, an impact which may never be observed or observed only after many years of exposure. Conversely, if a numerical standard is exceeded, it may not be at all significant and may not warrant discarding the source or going to great cost to reduce the concentration. The fact that the WHO standards and many country standards are all different, as shown in Tables 5-1 and 5-2, is a sign of uncertainty. Accordingly, the standards should be used as guidelines to help identify water that may be potentially harmful and to urge planners that waters with the fewest contaminants at the lowest concentrations are to be preferred to waters that have higher concentrations of more contaminants, even if they both fall within the limits of the standards.

> **Note:** The local manual should present a table with the national standards and guidelines.

Many new chemicals are entering the aquatic environment. Even if there is as yet no standard for them, that does not indicate that they may not be hazardous. Standards are always changing; more contaminants are added and permissible levels are reduced. Planners are advised to consider the potential for future contamination before making important decisions as to the adequacy of the quality of a water source.

In evaluating water quality for rural water supplies, planners should keep in mind that standards have been derived primarily for urban communities, where the limits are a compromise between needs for safety and economic factors, and where people are exposed to contaminants through other routes, such as food or the work place. Standards may be relaxed for rural communities where it may not be economically feasible to meet them. Industrial or commercial requirements that may govern urban standards are not likely to be applicable in rural communities. For example, slightly excessive color, turbidity, chlorides, etc. may not be so serious in rural communities that a high cost would be warranted to bring them within the standards.

The standards apply to the water delivered to the user. Some contaminants such as coliform bacteria and iron are easily removed; others, such as fluorides and synthetic organic chemicals are not. For this reason raw water quality is important.

An important clue to water quality problems is the health status of the population in a region. Waters in certain areas are prone to give problems and these should be identified early in the planning process.

Table 5-1 Water Quality Parameters

Microbiological and biological quality

Organism	Unit	Guideline value	Remarks
I. Microbiological quality			
A. Piped water supplies			
A 1 Treated water entering the distribution system			
faecal coliforms	number/100 ml	0	turbidity < 1 NTU, for disinfection with chlorine, pH preferably 8 0, free chlorine residual 0 2 0 5 mg/litre following 30 minutes (minimum) contact
coliform organisms	number/100 ml	0	
A 2 Untreated water entering the distribution system			
faecal coliforms	number/100 ml	0	
coliform organisms	number/100 ml	0	in 98% of samples examined throughout the year—in the case of large supplies when sufficient samples are examined
coliform organisms	number 100 ml	3	in an occasional sample, but not in consecutive samples
A.3 Water in the distribution system			
faecal coliforms	number/100 ml	0	
coliform organisms	number/100 ml	0	in 95% of samples examined throughout the year in the case of large supplies when sufficient samples are examined
coliform organisms	number/100 ml	3	in an occasional sample but not in consecutive samples
B Unpiped water supplies			
faecal coliforms	number/100 ml	0	
coliform organisms	number/100 ml	10	should not occur repeatedly, if occurrence is frequent and if sanitary protection cannot be improved, an alternative source must be found if possible
C Bottled drinking-water			
faecal coliforms	number/100 ml	0	source should be free from faecal contamination
coliform organisms	number/100 ml	0	
D Emergency water supplies			
faecal coliforms	number/100 ml	0	advise public to boil water in case of failure to meet guideline values
coliform organisms	number/100 ml	0	
Enteroviruses	—	no guideline value set	
II. Biological quality			
protozoa (pathogenic)	--	no guideline value set	
helminths (pathogenic)	—	no guideline value set	
free-living organisms (algae, others)	—	no guideline value set	

Table 5-1 (continued)

Inorganic constituents of health significance

Constituent	Unit	Guideline value	Remarks
arsenic	mg/l	0.05	
asbestos	—	no guideline value set	
barium	—	no guideline value set	
beryllium	—	no guideline value set	
cadmium	mg/l	0.005	
chromium	mg/l	0.05	
cyanide	mg/l	0.1	
fluoride	mg/l	1.5	natural or deliberately added, local or climatic conditions may necessitate adaptation
hardness	—	no health-related guideline value set	
lead	mg/l	0.05	
mercury	mg/l	0.001	
nickel	—	no guideline value set	
nitrate	mg/l (N)	10	
nitrite	—	no guideline value set	
selenium	mg/l	0.01	
silver	—	no guideline value set	
sodium	—	no guideline value set	

Organic constituents of health significance

Constituent	Unit	Guideline value	Remarks
aldrin and dieldrin	μg/l	0.03	
benzene	μg/l	10[a]	
benzo[a]pyrene	μg/l	0.01[a]	
carbon tetrachloride	μg/l	3[a]	tentative guideline value[b]
chlordane	μg/l	0.3	
chlorobenzenes	μg/l	no health-related guideline value set	odour threshold concentration between 0.1 and 3 μg/l
chloroform	μg/l	30[a]	disinfection efficiency must not be compromised when controlling chloroform content
chlorophenols	μg/l	no health-related guideline value set	odour threshold concentration 0.1 μg/l
2,4-D	μg/l	100[c]	
DDT	μg/l	1	
1,2-dichloroethane	μg/l	10[a]	
1,1-dichloroethene[d]	μg/l	0.3[a]	
heptachlor and heptachlor epoxide	μg/l	0.1	
hexachlorobenzene	μg/l	0.01[a]	
gamma HCH (lindane)	μg/l	3	
methoxychlor	μg/l	30	
pentachlorophenol	μg/l	10	
tetrachloroethene[d]	μg/l	10[a]	tentative guideline value[b]

Table 5-1 (continued)

Organic constituents of health significance (continued)

Constituent	Unit	Guideline value	Remarks
trichloroethene[d]	μg/l	30[a]	tentative guideline value[b]
2,4,6-trichlorophenol	μg/l	10[a,c]	odour threshold concentration 0.1 μg/l
trihalomethanes		no guideline value set	see chloroform

[a] These guideline values were computed from a conservative hypothetical mathematical model which cannot be experimentally verified and values should therefore be interpreted differently. Uncertainties involved may amount to two orders of magnitude (i.e., from 0.1 to 10 times the number).

[b] When the available carcinogenicity data did not support a guideline value, but the compounds were judged to be of importance in drinking-water and guidance was considered essential, a tentative guideline value was set on the basis of the available health-related data.

[c] May be detectable by taste and odour at lower concentrations.

[d] These compounds were previously known as 1,1-dichloroethylene, tetrachloroethylene, and trichloroethylene, respectively.

Aesthetic quality

Constituent or characteristic	Unit	Guideline value	Remarks
aluminium	mg/l	0.2	
chloride	mg/l	250	
chlorobenzenes and chlorophenols		no guideline value set	these compounds may affect taste and odour
colour	true colour units (TCU)	15	
copper	mg/l	1.0	
detergents		no guideline value set	there should not be any foaming or taste and odour problems
hardness	mg/l (as $CaCO_3$)	500	
hydrogen sulfide		not detectable by consumers	
iron	mg/l	0.3	
manganese	mg/l	0.1	
oxygen—dissolved		no guideline value set	
pH	—	6.5–8.5	
sodium	mg/l	200	
solids—total dissolved	mg/l	1000	
sulfate	mg/l	400	
taste and odour	—	inoffensive to most consumers	
temperature		no guideline value set	
turbidity	nephelometric turbidity units (NTU)	5	preferably <1 for disinfection efficiency
zinc	mg/l	5.0	

Source: WHO (1984), VI

Table 5-2 Compsrison of Chemical and Physical Drinking Water Standards Recommended by the WHO, USA, and Several Developing Countries

CHEMICAL AND PHYSICAL STANDARDS	WHO (1984) RECOMMENDED STANDARDS	USA 1976 INTERIM USA 1962	INDIA (1973)	INDIA RECOMMENDED (1975)	KOREA	PHILIPPINES (1963)	QUATAR	TANZANIA (TEMP.) 1974	THAILAND
Total hardness (meq/1) 1 meq/1 = 50 mg/1 as $CaCO_3$	<10		12	12	6			12	6
Turbidity (NTU)	5	1-5[a]			2		5	30	5
Color (platinum-colbalt scale)	15				2		20	50	20
Iron, as Fe(mg/1)	0.3	0.3[b]	1	1	0.3	1	0.3	1	0.5
Manganese, as Mn (mg/1)	0.1	0.05[b]	0.5	0.5	0.3	0.5	0.3	0.5	0.3
pH	6.5-8.5		6.5-9.2	6.5-9.2		6.5-9.2		6.5-9.2	6.5-8.5
Nitrate, as NO_3 (mg/1)	45	45[a]	50	45	45	50		100	45
Sulfate, as SO_4 (mg/1)	400		400	400	200	400	250	600	250
Flouride, as F (mg/1)	1.5	1.4-2.4[a]	2.0	1.5	1.0	1-1.5	1.6	8.0	1-1.5
Chloride, as Cl (mg/1)	250	250[b]	1000	1000	150	600	250	800	330
Arsenic, as As (mg/1)	0.05	0.05[a]	0.2	0.05	0.05	0.2		0.05	0.05
Cadmium, as Cd (mg/1)	0.005	0.01[a]		0.01		0.01		0.05	
Chromium (mg/1)	0.05	0.05[a]	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Cyanide, as Cn (mg/1	0.1	0.01[b]	0.01	0.05		0.01		0.2	0.2
Copper, as Cu (mg/1)	1.0	1.0[a]	3.0	1.5	1.0	1.5	0.3	3.0	1.0
Lead, as Pb (mg/1)	0.05	0.05[a]	0.1	0.1	0.1	0.1	0.1	0.1	0.05
Magnesium, as Mg (mg/1)	150		150	150		150	125		125
Mercury, as Hg (mg/1)	0.001	0.002[a]		0.001					
Selenium, Se (mg/1)	0.01	0.01[a]	0.05	0.01		0.05		0.05	0.01

Source: adapted from World Bank, 1977

5.1 Drinking Water Standards

Physical, chemical, and microbiological parameters are included in most standards. Parameters can be classified as those of health significance, such as fluorides, lead, and coliform organisms, and those that affect appearance or economic quality, such as color, turbidity, hardness, and iron. While the latter are not of health significance they are important because they affect the usefulness of the water and they may force the consumer to obtain water of better physical quality from an alternate source, which might be less safe.

Because sources of water for rural communities may be limited, it is worthwhile to distinguish between water quality standards of health significance which should be mandatory and those that are not which would be optional.

Synthetic Organic Chemicals (SOCs)

The appearance of synthetic organic chemicals in both surface and ground water sources is characteristic of industrialized countries. Many of these have been shown to be carcinogenic, mutagenic and teratogenic. They enter water sources from urban and industrial areas, from leaching of hazardous waste landfills and from the extensive use of agricultural biocides.

Because of the wide variety of such chemicals, no single test can be adequate. Accordingly, if there is any likelihood that such chemicals are present, one of several tests might be performed: total organic carbon, gas chromatograph or carbon chloroform extract. If organics appear to be a problem, a central laboratory to serve the rural water supplies should analyze and make recommendations concerning synthetic organic chemicals. However, SOCs are not likely to be a problem for most rural supplies in developing countries.

Trihalomethanes (THMs)

This category of organics, which includes chloroform, is formed by the reaction of chlorine used for disinfection with organic matter, such as humic materials, which are responsible for color, in the raw water. THMs can be kept to a minimum by removing color and turbidity to low levels which reduces the potential for the formation of THMs by reducing both the organic precursors and the chlorine demand. A standard for THMs of 0.1 mg/l has recently (1982) been introduced in the US. However, because of the difficulties of meeting this standard, it does not yet apply to communities of under 10,000 population. (This is an example where standards are relaxed for small communities.) For water supplies in regions where water-borne infectious diseases are present, the availability of chlorine and the practice of chlorination is more important than THM formation.

Fluorides

The recommended standard of fluorides of 1.5 to 2.0 mg/l is intended to be low enough to prevent fluorosis and high enough to prevent dental disease in children. Fluorides are added to some water supplies. This standard needs to be examined critically before a decision to add fluorides is made, as fluorides may be present in many foods, so that an optimum intake, or even an excessive intake, may be present without any intake from water supplies. Accordingly, the fluoride standard for drinking water should be adjusted to the locality. Public health officials need to be called upon for guidance in characterizing the fluoride situation in the region.

A major problem in many rural water supplies is excessive fluorides leading to severe bone damage. The high cost of defluoridation may warrant search for alternative sources.

Heavy Metals

Many of the heavy metals are toxic. They tend to be present in water supplies in only certain localities, and in those localities they require continued attention. However, lead is ubiquitous and is found in water supplies throughout the world. Lead is particularly important because it is highly toxic and has been shown to cause neurological damage in children leading to intellectual and psychological impairment, even at extremely low exposures. No safe threshold exists for lead, as any lead exposure is damaging. Therefore, the lead concentration in water should be as low as possible.

Aluminum is not generally included in drinking water standards but it is beginning to be considered to be important because of its association with problems of the central nervous system. While aluminum is widely present in soils, its presence in water is of special concern where alum is used for coagulation. Residual aluminum is minimized when coagulation is performed properly, and it should not exceed 0.2 mg/l. Higher residual aluminum values are indicative of poor coagulation

Bacteriological Standards

Most residual chlorine standards, 0.3 mg/l after 30 minutes at normal pH, will generally produce water with fewer coliform than most standards call for. Monitoring for chlorine residuals after treatment and in the distribution system provides a simpler, cheaper, and more rapid assurance of bacterial quality than bacteriological testing.

Where the only treatment is to be disinfection, coliform in the raw water should not average more than 1000/liter, and they should not average more than 10,000/liter when full treatment is to be provided.

Bacteriological standards may be more important and may need to be tighter in developing countries than in industrial countries because the potential for the spread of infectious disease is so much greater.

> **Note:** The health agency should decide whether chlorination is required for all water supplies, or at least for all surface supplies. A standard for free or combined chlorine should be promulgated.

Radioactivity

While no standard may be necessary for radioactivity, groundwaters abstracted from aquifers in radioactive soils, or surface waters abstracted downstream of nuclear establishments or hospitals that use radioactive isotopes, may need to be examined for radioactivity.

5.2 Sanitary Survey

A sanitary survey of the available sources of water is as important as determining the quality parameters. A most important principle is that a water supply should be obtained from the most desirable source which is feasible, and efforts should be made to prevent pollution of the source. A sanitary survey assesses the source, identifies activities on the watershed and the existing and potential sources of pollution, and provides guidance as to the samples that need to be collected and the analyses that need to be made to characterize the quality of the source.

Without a sanitary survey, the fact that a water meets the numerical standards does not give assurance that the water will be safe for long term ingestion. A well or spring may permit surface drainage to enter, but contamination will be detected only after a rain. The presence of an industrial complex on the watershed may mean that a wide variety of chemicals may be found in the water, snf new chemicals may be introduced at a later date. Agricultural pesticides may be present in water in a river at only certain times so that analyses may not reveal their presence whereas the sanitary survey will.

> **Note:** The currently applicable stream and effluent standards where available should be referenced in the manual, with direct quotes of applicable sections.

Physical Survey

The principal element of the survey is the preparation of a map of the watershed of the surface supply or the recharge area of the groundwater supply. The map should show the land uses and identify the activities and the points of wastewater discharge. If industries are present, materials used by the industry should be identified. These will provide information as to whether the effluents should be analyzed and which contaminants should be sought. Nonpoint sources of pollution, such as urban and agricultural runoff, are more difficult. For the latter, identification of the fertilizers and biocides used can offer a guide as to contaminants present. Storm drain outlets in the watershed can be sampled during rains to determine the extent of pollution from urban runoff. Even where no urban or industrial pollution is present, examination of the soils may provide information on fluorides, radioactivity, or certain metals.

The physical survey provides a baseline to monitor changes after the water facility is constructed. Most of all, it assists in selecting the best water source from among alternatives.

Among the sources of pollution that may be present are: residential developments, street runoff and sewer outfalls; urban developments, runoff and sewer outfalls; industry, runoff and sewer outfalls; agricultural activities; mines and quarries; waste disposal in landfills, particularly hazardous wastes; transportation, including boats on the water, trains, roads; and construction activities.

Chemical Survey

Data from river and groundwater monitoring should be obtained to provide information on potential problems in the watershed or the aquifer. If there are no data, steps should be taken to initiate monitoring. The parameters to be determined should be agreed upon between the local water supply agency and the pollution control agency that is responsible for ambient water quality monitoring.

Biological Survey

Chemical discharges are often intermittent, and occasional sampling at an outfall or in a river may miss them. The fauna in a river, particularly fish, integrate the chemicals that flow in a river. Examination of fish and other biota will often reveal the presence of pollutants in a water source that would otherwise be missed.

5.3 Monitoring Water Quality

The analysis of raw and finished water after the system is in operation is a function of the plant officials and/or the regulatory (health) agency. In planning a water supply facility, provision needs to be made for easy sampling of raw and finished water, storing of samples, analysis at the plant for tests that are a guide to operation, transportation to a central laboratory of samples that are of health significance and a measure of performance.

Samples should be collected in appropriate vessels from conveniently located sampling taps rather than being pumped in sampling pipe lines, because the quality of a water changes as it flows through the sample pipe. Raw water and effluent samples should be collected, the latter at least 30 minutes after the addition of the final chlorine dose, to provide adequate contact time.

Provision needs to be made for collection of samples of treated water from various points in the distribution system. These should be conveniently located so that easy access is available.

> **Note:** Identify the agency responsible for pollution monitoring.

5.4 Raw Water Quality Problems and Treatment

Groundwater

Groundwater quality is usually bacteriologically good but sometimes poses chemical problems because of the nature of the aquifer. Occasionally, manmade pollution may be a problem. The character of a groundwater changes only slowly over time so that terminating pollution of an aquifer will not restore its quality for a considerable period. The most common quality problems and how they are addressed are listed below.

Fluorides. Excessive fluorides are a problem in some regions. Several approaches for defluoridation are available, although there is little experience with them because of their high cost:

(1) ion exchange with activated alumina or bone char, which require regeneration;

(2) removal of fluoride with magnesium by the addition of lime, often done incidental to softening; and

(3) alum coagulation, with controlled pH and coagulant aids.

The best solution is the selection of another source or a different aquifer.

Iron and manganese. These are a frequent problem, but their removal is simple and often accomplished by methods widely used for surface water treatment:

(1) aeration followed by filtration and chlorination; or

(2) aeration, coagulation, sedimentation, filtration, and chlorination.

Except for the introduction of aeration, to oxidize the soluble ferrous iron to the insoluble ferric iron, the treatment is conventional.

Hardness. The softening of water was important at one time to make clothes washing easier and more economical. With synthetic detergents, softening is no longer necessary. Furthermore, indications are that those who use hard water exhibit lower rates of heart disease than those who use soft water, which would suggest that softening may not be appropriate. Two methods of softening are available:

(1) lime-soda softening, which includes processes of coagulation, sedimentation, filtration and disinfection; and

(2) ion exchange, which is generally more costly and not recommended because the calcium and magnesium are replaced by sodium, resulting in high sodium levels that may be troublesome to those with heart disease who are on low-salt intake regimens.

Brackish water. Occasionally groundwaters are excessively high in salt. Several approaches are available, all exceedingly costly:

(1) electrodialysis;

(2) reverse osmosis;

(3) distillation.

None of these are appropriate for rural supplies, and should be called upon only in emergency situations. Where a potential source contains excessive salt, the best solution is generally the development of another source.

Synthetic organic chemical contamination. Such waters are best avoided. Coagulation, sedimentation and granulated activated carbon filtration, aeration, and/or reverse osmosis may be called upon. Treatment systems need to be designed specifically to attack the particular contamination problem.

Bacterial contamination. Where standards call for a chlorine residual, all water supplies must be chlorinated. A free chlorine residual of 0.3 mg/l after 30 minutes is generally adequate if the water is low in turbidity and the pH is low. Generally surface waters need chlorination while protected groundwaters do not.

Surface Water

Almost all surface waters require filtration. A surface water drawn from an isolated, uninhabited, forested, well protected watershed not subject to silt runoff with each rainstorm may not require filtration, but such water sources are rare. However, even such sources require chlorination. To assure adequate disinfection with chlorine, if turbidity is present, filtration may be necessary. In such instances, direct filtration is used: a small dose of coagulant, with a coagulant aid, is added to the water as it is applied to the filter, is followed by chlorination. Flocculation and sedimentation are omitted. Such waters may also be treated by slow sand filtration. Most surface waters require conventional treatment: chemical addition, rapid mixing, flocculation, sedimentation, filtration and disinfection.

Where sources are heavily polluted, the incorporation of granular activated carbon filters may be necessary, but they are not appropriate for rural supplies. The best solution for polluted sources is the development of an alternate source of higher quality.

Chapter 6

System Capacity

6.1 Factors Influencing Capacity

The capacity of a water supply system is based on anticipated water demand. In regions where water resources are inadequate, and where communities are without water service and without sufficient financial resources to provide a system that can meet all anticipated demands, the capacity to be provided will be governed to a large extent by the cost of providing a system. Where water of good quality is plentiful and easily developed, and where financial resources are ample, the capacity to be provided may be much greater.

Other factors that influence the capacity of the system are (a) the design period, which fixes the target date in the future for which the project must serve; (b) the population at the target date; (c) requirements for institutions, commerce, industry, and agriculture; (d) the level of service to be provided, whether full-service house connections, yard taps, or public standposts; and (e) climatological variations. These factors are discussed below.

Design Period

A decision must be made as to the target year that is to be the basis for design. The optimal design period for rural water systems in developing countries is generally about 7 to 8 years. In addition, 2 to 3 years must be allotted for lead time, the time for the project to be planned, designed, constructed, and placed into operation, making a total of about 10 years from the initiation of planning. The design period may be modified by the following factors:

(a) The design period of elements of a system can be reduced if they can be easily enlarged. For example, water transmission capacity can be increased by adding another line, or a treatment plant can be enlarged by adding another module, so the first units can be designed for a shorter period. However, a dam or an intake is not easily enlarged, so they should be designed for their full useful life.

(b) The economy of scale of the system or an element of the system can affect the design period. If increasing the capacity of an element of a system 50% only increases the cost 10%, which is often the case with pipelines, where the costs of excavation, installation and backfilling are little affected by the size of the pipes, then the pipe may be designed for a capacity required further into the future.

(c) The design period might be reduced if the growth of the community is expected to be rapid. For example, if a community is expected to increase three-fold in 10 years, the cost burden to build for a 10-year period would be very heavy on the present residents of the community. A shorter design period would permit the new residents to participate financially in the system expansion. On the other hand, if the community is not expected to grow, the additional cost of providing for a longer design period would be small.

(d) A high rate of interest for the money to be borrowed tends to reduce the design period because the higher cost of money will be a heavier burden.

(e) The useful life of the component structures and equipment can affect the design period of the elements of the system. A pump with an expected life of 15 years should be designed for that period of useful life. If it were designed with a smaller capacity, it would need to be replaced before it is worn out. If it were designed with a larger capacity, it would be worn out before its full capacity would be needed.

Accordingly, design periods for major elements of the project should be selected at the very start of the planning, so that the population to be served at the end of the design period, upon which the size of the project is to be based, can be decided.

In general, the useful life of individual system components is approximately as follows:

Pumps	10-15 years
Pump buildings	20-25 years
Pipe lines - cast iron	45-50 years
- plastic	15-20 years
Dams and intakes	40-50 years
Wells	20-25 years
Treatment plants	20-25 years

For planning purposes, the target year, unless changes are indicated, should be taken as 10 years following the initiation of project planning.

Population Estimates

An important factor in establishing the capacity of a system is the population to be served in the target year at the end of the design period, including the lead time.

The factors to be included in the population estimate are the present population and the anticipated rate of population growth. While the present population is easily estimated, the rate of growth is uncertain because it depends on family planning policies, migration into or out of the community, local and national economic conditions, and on growth or changes in production activities which may be decided at the local, provincial or national level.

The service area also influences population growth. The project may be planned to incorporate other nearby communities that are in need of water service, either because they are not likely to obtain their own facilities, or because their being included in the project will reduce per capita costs. Such regional planning considerations are especially important for projects requiring dams, long transmission mains or treatment works, as the economies of scale reduce the unit cost. This is less appropriate for well supply systems.

Institutional, Commercial, Industrial, and Agricultural Requirements

Water demand includes, in addition to household uses, the normal associated community needs such as for schools, health clinics, offices, and the service establishments for the community. In addition, significant demands may be imposed on the system for manufacturing, industrial, and agricultural enterprises, plus activities of individual families who raise animals or grow gardens requiring irrigation. (Agricultural irrigation in general is not included, because such water is generally obtained from other sources and need not be of drinking water quality.) Projecting all these requirements to the end of the design period is difficult but necessary.

Levels of Service

The demand for which the project must be designed is the sum of all the water uses mentioned above plus an allowance for water used in treatment and unaccounted for water which results from unmetered wastage and from leakage, both of which should be held to a minimum.

Household water use is a function of the level of water and sanitation service. Where residents use public standposts, the per capita use is much less than if each household has a piped water service. Similarly, if pit latrines are to be used, the per capita household use will be substantially less than if flush toilets are introduced.

On the other hand, where piped water to households is to be provided, it can be expected that, in some places, residents will add water-using devices such as washing machines, showers, etc. which will increase the demand before the end of the design period is reached. The impact of this increased level of service should be considered by the project planner, and judgements made on how it would affect future demand.

Climatological Variations

Water use is also a function of climate, with greater per capita use in hot, dry zones as compared with cold, wet zones. The differences between the zones are likely to be much more pronounced where the domestic supply is used for animal and garden watering.

6.2 Average Demand

The average demand is the total of household residential demand, requirements for institutions, commercial and industrial establishments, and household and village watering and, in some cases, household agricultural use. The average demand is used only for determining the adequacy of the source and then only when seasonal storage is available. The maximum daily demand is used as the basis for design capacity for most other elements of the system.

Household Demand

Evaluation of water use in existing communities in various climate zones in the country will indicate actual demands for various levels of service in these zones. Illustrative values for per capita use in households for various levels of services are shown in Table 6-1.

Table 6-1 Average Daily Per Capita Household Consumption (liters per day)

Area	Public Standpost	House Connection[a]
Humid	10-20	20-40
Average	20-30	40-60
Dry	30-40	60-80

[a]Without flush toilets and not including allowances for private irrigation, animal watering or other enterprise.

Note: The local manual should indicate average residential water demand for different levels of services in different zones in the project area.

In addition, special local demand may have to be considered where water is used for animals and for irrigating household garden plots, especially in arid areas but also in humid regions where the piped water is more convenient than water available in canals and ponds. Table 6-2 shows water requirements for household animals.

Table 6-2 Typical Water Use by Household Animals (liters per head per day)

Animal	Amount	Animal	Amount
Sows	80-90	Mules, horses	40-45
Boars	16-18	Poultry	0.2
Hogs	30-33	Sheep, goats	5
Water buffalo	60-66	Oxen	16-18

Metering and a tariff structure with increasing unit rates for higher usages of the piped potable water will help reduce the demand for its use for irrigation and animal watering.

Water for urban irrigation, including garden plots and other green space, is a function of the plants grown, the soil, and the climate. Such data can be obtained from local agricultural agencies. An option to be considered in the planning is the consideration of using waste washwater, "gray water", for household irrigation. In water-limited areas, the reclamation of wastewaters for irrigation should be considered and evaluated.

Institutional and Commercial Demand

Institutional water demand is highly variable, depending upon the nature of the institution, the number of people served in the facility, and the level of service provided. Table 6-3 provides guidelines for typical community institutions with piped water into the facility.

Table 6-3 Typical Water Use in Community Institutions

	Without Flush Toilets	With Flush Toilets
Schools		
Community Centers		
Health Clinics		
Restaurants		
Laundries		

Note: The local manual should indicate estimates of these values based on local conditions.

nndustrial Demand

Industrial water demand varies considerably with the type of industry and with the degree of recycling of water within the plant, especially for cooling water. Table 6-4 provides guidelines for typical industries, but the industries themselves are better sources of data. If industries have been obtaining their own water, but expect to switch to the community water supply, they must immediately be required to meter their water use. Where industry is served by the community water supply, recycling and other methods to economize on water use can be encouraged through metering and charging.

The planner must discuss with the community whether the industry should be included in the water project. Including industry is generally advantageous because of economies of scale and because a greater investment can be justified in developing a source that may be of higher quality. If the industry does not require water of drinking water quality, the system can be designed to provide raw water to the industry and treated water from the same source to the community.

Table 6-4 Typical Industrial Water Use (liters per unit)

Industry	Amount
Beet sugar	30,000 per ton of beets
Meat slaughtering and packing	30 per kg live weight
Milk processing	4500 per 1000 liters
Cotton goods	10 to 50 per kg cotton product
Tanneries	50 to 2500 per sq. meter of hide
Paper	100,000 to 500,000 per ton of product
Laundries	30,000 to 50,000 per ton of laundry

Note: The above are illustrative. The local manual should include data obtained from typical local installations.

Unaccounted for Water, Including Leakage

In addition to all the specific water uses listed above, an allowance for unaccounted for water, including leakage and unmetered wastage, must be made. The quality of construction and maintenance and the pressures to be maintained have an impact on losses. In general, a 10 to 20% allowance is appropriate if precautions are taken to control water losses. If a rapid filtration water treatment plant is to be provided, an allowance of about 5% for water supply for the plant should be provided.

Average Community Demand

For a design population of about 3000 people, without any special requirements for institutions, industry, or irrigation, the base average annual demand may vary from about 200 m^3/day to about 400 m^3/day for house taps without flush toilets. A system with only public taps may require about 30 to 100 m^3/day. Household flush toilets, institutional, irrigation, and/or industrial requirements increase these figures substantially.

Total Average Demand

A table should be prepared as follows to help establish the average demand, after the level of service, population, animal, irrigation, institutional, industrial and other uses have been estimated. Table 6-5 indicates the calculation for a typical small village without any special water requirements; Table 6-6 applies to a community with special requirements.

Table 6-5 Average Daily Demand for Typical Communities

	Present (Year =)			Target Year (Year =)		
	W	S	A	W	S	A
Population						
Domestic demand*, lcd						
Average daily domestic demand, m^3/day						
Normal commercial and institutional demand,** m^3/day						
Unaccounted for water and leakage**, m^3/day						
Total community demand, m^3/day						

W = Winter S = Summer A = Average

*Includes household animal watering and irrigation

**Estimated at 20% of average daily domestic demand

Table 6-6 Average Daily Demand for Communities with Industrial or Other Requirements

	Present (Year =)			Target Year (Year =)		
	W	S	A	W	S	A
Population						
Domestic demand,* lcd						
Average daily domestic demand, m^3/day						
Industrial demand, m^3/day						
Commercial demand, m^3/day						
Institutional demand, m^3/day						
Agricultural demand, m^3/day						
Unaccounted for water, leakage, etc.**, m^3/day						
Total demand, m^3/day						

W = Winter S = Summer A = Average

*Includes estimated household animal water and irrigation
**Estimated at 20% of community demand

Estimates of present use may be difficult to make, but such estimates are likely to be much more precise than estimates of future use. Estimates of present use help provide estimates for the future and help illustrate their uncertainty, so that too much precision is not used for design.

6.3 <u>Maximum Daily Demand or Design Capacity</u>

Water use varies with the seasons, and with the hours of the day. Fluctuations are greater in small communities than in large, and in arid over humid areas. Variations are generally expressed as ratios to the average.

The rate of maximum daily demand, which is generally the same as the rate of maximum seasonal demand, is the single most important design parameter, as it determines the required capacity of the intake, well, raw water pumping station and transmission mains, treatment works and, if there is adequate elevated storage, the finished water transmission mains. It is called the design capacity. The distribution system is based on the peak or maximum hourly demand as discussed below. The maximum day factor is

$$K_{max\ day} = \frac{\text{maximum daily demand}}{\text{average daily demand}}$$

In rural communities, the maximum daily demand usually varies from 1.2 to 2 times the average day demand. In general, the lower value applies in communities that use little water for irrigation. If much of the water is used by an enterprise whose demand for water is relatively constant over the year, the lower factor will likely be more appropriate. On the other hand, enterprises in a community that exhibit higher demand in the dry season tend to require a higher maximum day ratio.

If the water produced for a community is metered at the source or at the treatment plant, and all supplies should be metered, a determination of the ratio of maximum to average day is easily made. Data from similar nearby communities can be the basis for selecting the appropriate ratio to use. Because the maximum day requirement is so much a function of climate and region, the data should be collected and analyzed by regions.

In the absence of any data, a factor of about 1.5 is appropriate. However, it must be recognized that this may result in a system that may be 1/3 smaller or larger than necessary. Hence data from nearby communities is desirable to avoid excessive design or inadequate capacity.

> **Note:** Typical values of maximum day ratios by provinces or regions should be incorporated in the manual.

Based on a community of 3000, without excessive allowances for institutions, irrigation, or industry, the maximum day demand (design capacity) may vary from about 240 to 600 m^3/day for house connections and about 60 to 120 m^3/day for systems with only public taps. The design capacity value for illustrative purposes in this manual is taken as 240 m^3/day or 10 m^3/hour.

6.4 Peak or Maximum Hourly Demand

The peak demand, sometimes referred to as the maximum hourly demand, determines the capacity of the distribution system and service reservoirs. In the absence of any elevated service reservoir, the pumps that deliver water to the distribution system must also be designed for the peak demand. With adequate elevated service storage, these pumps need only meet the maximum day demand.

The peak demand results from either peak domestic use or water for fire-fighting plus coincident domestic demand. These peaks are not additive as it is not likely that water will be required for fire-fighting at the same time as high domestic use is occurring.

Fire-Fighting

In small communities, water demand for fire-fighting is far greater than the peak domestic demand, so the provision of capacity for fire-fighting adds significantly to the cost and is generally not justified. However, a hydrant in the center of the community can be useful in making water in the system available for emergency use. Mobile fire pumps can be used to draw water from canals or ponds in the community as well as the hydrant.

The provision for fire-fighting increases the cost of small systems considerably (Hebert, 1985). Accordingly, the benefits would need to justify such an investment, particularly where ponds or canals can provide water for fire-fighting at lower cost.

Peak Domestic Demand

The peak domestic demand generally occurs during the maximum day, and results from the simultaneous use of water by consumers. The peak demand factor is

$$K_{peak} = \frac{\text{rate of water demand in peak hour on maximum day}}{\text{average rate of water demand on maximum day}}$$

The peak demand tends to be much greater in a community whose residents work in a factory which has established hours of employment. If employees are all released from work at about the same time, the residents will tend to draw water for bathing, cooking, and garden watering at about the same time. The peak will also be influenced by institutional and industrial practices. If a substantial portion of the water produced is for a factory with a uniform 24-hour demand, the variation will be relatively small. Accordingly, it is difficult to generalize as to the peak demand factor.

Whereas it is simple to obtain data for calculating the maximum day factor, data for the peak demand factor are more difficult to determine, particularly where some of the peak demand is met by drawing water form an elevated storage tank. However, such data can be obtained by reading master meters continuously or hourly, and adjusting for changes in level in the elevated storage tank. In the absence of specific data, the peak demand design factor is taken as 2.

For a community of about 3000 people, without consideration of fire-fighting, this would require a peak rate for design varying from about 20 to 50 m^3/hour for a system with house connections. For illustrative purposes, the peak demand is taken as 20 m^3/hour. The spread is so great that more specific guidelines based on local data would be helpful.

> **Note:** The local planning manual should indicate local peak demand factors based on local data.

6.5 Demand Modification

The provision of piped water available continuously in a community where people previously carried water increases the demand and waste of water substantially. Accordingly, a program of conservation should be instituted at the outset. Conservation is necessary even where water is plentiful, as pumping and treating water that is not needed adds unnecessarily to the cost. The following measures are applicable:

Metering

To manage water effectively, it must be metered (1) as it is abstracted from the source; (2) after treatment as it is delivered to the community; and (3) at all points of use, including community uses. The only exception is water for fire-fighting which, though used at a high rate, is small in quantity. Master meters should be read regularly, preferably daily, and consumers' meters monthly so that most water provided can be accounted for. If unaccounted for water is more than about 20%, measures must be taken to find the reason and make corrections. Metering can identify wasteful users so that they can be obliged to use water properly and repair leaks.

Charging

An effective way to conserve water is to charge all users, even community users, for metered water. If the charge is meaningful, it discourages waste. Where water is limited, a charging system can be devised that provides a base amount of water per month at a certain price and a higher unit price for all use in excess. This is particularly effective in arid, water-short areas that have high demands for irrigation (Chapter 15).

Large users, such as factories, must be metered. By making a surcharge for peak demands, they can be encouraged to provide their own storage for peak demands.

Leakage Control

All systems leak. Detection of leaks can be assisted by metering which identifies losses. Location of leaks can be accomplished by pressure testing and by leak detectors (Chapter 14).

Flow Restriction

Flow restrictors can be installed in household service lines to reduce peak demand. They are designed to supply each connection with the maximum daily demand over a period of 24 hours. This design results in savings in system costs, as all system components can then be designed based on the maximum daily demand, with a peak hour factor of 1.0. It requires, however, that connected households provide storage tanks to meet their peak demands, the total cost of which may offset system savings.

If the use of water restrictors is considered in a project, their performance should be tested by pilot systems. For example, most of the restrictors used in a project in Indonesia were modified by householders to increase the flow to avoid costs of private storage (Lauria, 1985). Furthermore, a restricted service is less desirable than full service and willingness to pay may be reduced.

Chapter 7

Selection of Source

The most important guideline in selecting a source is that it be of the highest quality that is technically and economically feasible. Dependence on treatment to assure quailty should be minimized.

The selection of the source involves evaluation of its adequacy and reliability, its quality, its distance from the community to be served, whether it can serve the community by gravity or requires pumping, its vulnerability to natural hazards such as flooding and freezing, and its accessibility. Final selection among sources that are adequate in quantity and satisfactory in quality rests upon cost and availability of funds for capital investment. A high capital cost gravity system, with low operating costs may entail minimum annual costs, but the high first cost may be a deterrent in its adoption.

7.1 Sources of Water

Among the options for water sources are:

- water purchased from a nearby city or community that produces it, either raw or treated;
- water from a nearby irrigation project;
- groundwater, from springs, infiltration galleries, shallow wells or deep wells;
- surface water, from a small stream with or without an impounding reservoir, from a large river, estuary, or lake;
- direct precipitation catchment; or
- conjunctive use of two or more of the above sources.

Figure 7-1 shows a profile illustrating most of the sources available, including water-bearing formations, called aquifers.

Consideration should be given to joint enterprise with other nearby communities so that, together, the communities on a regional basis can develop a higher quality or a more economical source than would be feasible for each community to develop separately.

Individual household systems, such as roof catchments and shallow wells, are not included in the manual.

> **Note:** Another manual for individual supplies should be provided.

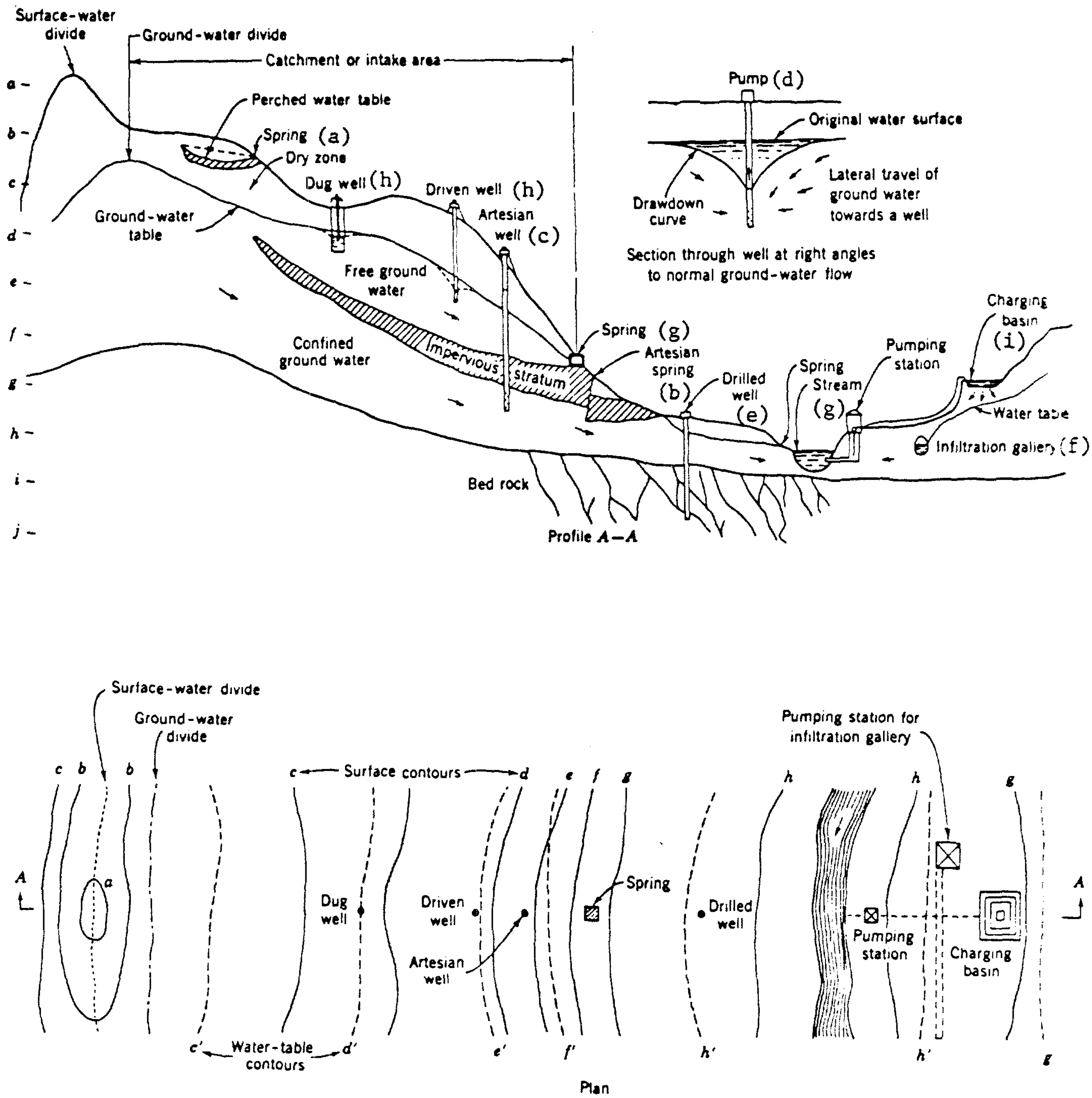
7.2 Basic Data

Source selection and development depends upon data concerning topography, precipitation, temperature, soil types and permeability, groundwater levels and recharge, and stream flows.

Topography

Topographical maps identify location and elevation of potential water sources in relation to the community, intake, transmission main and treatment plant sites; suitable sites for impounding reservoirs, if necessary; and sites

Figure 7-1 Groundwater and Its Development as Springs, Wells, and Infiltration Galleries



Source: Fair, Geyer, Okun (1966)

for elevated service reservoirs. They are also useful for making the sanitary surveys which identify developments on watersheds that may affect water quality. For the initial planning and surveys, maps of about 1:25,000 scale are useful, as they help identify and locate neighboring communities, entire watersheds and other features that affect water source selection and water supply development. For final planning, 1:5000 scale is preferred. Contour intervals should be 5 meters or less on the small-scale maps and 1 meter on the large-scale maps.

> **Note:** The local manual should indicate the agency responsible for providing topographic maps.

Geology

Geological and soils information is necessary for both ground and surface waters. This information should include soil types at the surface and the nature of the various underground strata. Such data may indicate

- potential water quality problems, such as excessive iron or fluorides;
- potential for silting, impacting on reservoirs or creating water treatment problems;
- permeability of strata, indicating their potential as a groundwater source;
- potential for earthquakes or other natural hazards; and
- suitability of sites as foundations for dams, pumping stations, treatment plant units, etc.

Of course, it may be necessary to make detailed studies at particular sites to obtain specific information as, for example, permissible bearing loads.

A useful source of information is from well logs. Whenever wells are drilled, well logs should be kept; samples of the soils at various depths should be analyzed to build up a record of subsoil conditions in an area.

> **Note:** All well drillers should be required to provide well logs and other pertinent data, such as water table depth, on all drilling operations. The manual should indicate the agency responsible for collecting these data.

Hydrogeologic Data

One reason that groundwaters, which are generally preferable in quality and cost to surface waters, are not used more frequently is that that data on their availability is more difficult to acquire and interpret than data on surface waters. Where data on groundwater levels are available, the preparation of water table contours can be plotted to help identify underground flow patterns.

When wells are constructed, data on groundwater levels and on yields from well testing should be collected. Among other data to be collected are thickness of aquifers, circles of influence when pumping wells, and depth to water level under varying pumping regimens, etc.

> **Note:** The local manual should identify the agency responsible for collecting these data.

Meteorological Data

Inasmuch as all fresh water originates from precipitation, the data on precipitation are useful in water supply planning, especially in the absence of hydrologic or hydrogeologic data. Annual average and daily precipitation data from rain gages near the communities to be served should be obtained for as many years of record as are available. Such data serve many purposes. They indicate the critical seasons for water availability; the potential surface water runoff where stream runoff data are limited; and the potential for rainwater catchments.

Recording rain gages indicate rainfall intensity which is important for predicting floods. In the absence of years of runoff records, measurements of rainfall intensity in mm/hour indicate the potential for flooding intakes and pumping stations. In addition to rainfall, data on snowfall is also necessary where snowmelt is a source of water.

Annual precipitation is highly variable, and many years of record are necessary to establish probabilities for any particular rainfall. The longer the record, the more reliable the prediction.

Evaporation and evapotranspiration data are also necessary. In arid areas, losses due to evaporation from reservoirs and evapotranspiration from trees and plants may be substantial. Calculations on yields from surface sources must incorporate these losses.

Temperature data are important where freezing is a problem either during construction or in operation.

Hydrologic Data

Stream runoff data are essential for determining the suitability of surface water supplies. Again, the longer the record, the more precise the predictions of runoff. With only a few years of runoff record and a longer rainfall record, it is possible to establish a relationship between runoff and rainfall from which runoff can be estimated based on the longer rainfall records.

Without an impoundment, the low flow in a stream is a measure of its safe yield. However, the safe yield is not a fixed value but is based upon the acceptable risk of suffering a shortage. In urban areas, a risk of being short one year out of 20, or 5% of the years, is generally acceptable. In rural communities, shortages in two out of 20 years, or 10% of the years, may be acceptable. In a year when the yield is less, emergency conservation measures are necessary. With greater risk, the safe yield of a source is greater and the cost of a supply is reduced. The definition of "safe yield" is a local planning and policy decision.

If the dry weather flow in a stream, which is on the order of 1% of the mean flow, is too low to provide the flow required during the maximum day, the design capacity, an impoundment is necessary to store water during wet periods. The size of an impoundment, and its cost, increases exponentially with the yield as it increases in percent of the mean annual flow. In general it is feasible to develop up to about 50 to 70% of the mean annual flow by impoundment. Reference books indicate the calculations necessary to compute the size of impoundment to assure yields between the minimum and mean flows.

While it may be feasible to analyze runoff data for each project, it is far more useful to generate runoff parameters on a regional basis, where the precipitation and topography are similar. For example, using all runoff data in a region, it is possible to obtain mean and minimum flows, as well as frequency data, using the parameter of runoff in m^3/day or l/sec per square kilometer. Then it is only necessary to determine the drainage area to obtain the mean or minimum flows at a proposed intake site to get the potential yield.

> **Note:** The manual should indicate the agency responsible to collect and evaluate hydrologic data. Also, if data are available, tables or charts should be included that show the size of impoundment necessary for a range of yields per square kilometer for various risk frequencies.

7.3 Groundwater Sources

Where available in adequate quantity and satisfactory quality, groundwater sources are preferred as they generally require less treatment than surface sources, are more easily protected, and can be closer to the community to be served.

Only when groundwaters cannot provide adequate yield or are high in fluorides, iron or manganese, radioactivity, salt or other troublesome constituents, or are subject to contamination from hazardous waste disposal sites, should they be passed over for surface sources.

The following are groundwater sources in general order of preference with regard to quality:

- Upland springs
- Artesian springs and wells
- Deep wells
- Infiltration galleries
- Shallow wells

Upland Springs (a in Figure 7.1)

Such sources are almost ideal as they are least likely to be contaminated and they are often at sufficient elevation to provide water by gravity. Intake structures are simple. Also, because the recharge area is generally more remote from populations than other sources, they can be more easily protected from despoliation. Of course, springs at low elevation, g as shown in Figure 7.1, may be of poor quality.

Artesian Springs and Wells (b and c in Figure 7.1)

Artesian sources are those in confined strata under pressure. When the upper confining stratum is perforated, the water rises above the water table. The recharge areas for artesian aquifers are some distance away at higher elevations.

An artesian spring discharges water under pressure. Artesian wells can be flowing or nonflowing. A flowing artesian well behaves like an artesian spring. In a nonflowing artesian well, the water level in the well is above the water table, but needs to be pumped.

A major advantage of artesian sources is that, because the aquifer is under pressure, it is not easily contaminated. The recharge area can be polluted but because it is generally a considerable distance from the point of extraction, it tends to be cleansed in flowing underground.

A major concern with artesian sources is their yield and the likelihood of their being overdeveloped. The larger the number of wells constructed in an artesian aquifer, the more water will be withdrawn, which will reduce the volume of water and lower the water table in the aquifer. Excessive withdrawals may, in fact, eliminate the pressure in the aquifer entirely.

Deep Wells (c, d, and e in Figure 7.1)

Deep wells may be in free (d) or confined (c and e) aquifers. Free aquifers are exposed to the surface while confined aquifers have an impermeable overlying stratum. (An artesian aquifer is a confined aquifer under pressure.) Wells in free aquifers are more subject to pollution than those in confined aquifers. Logging a well as it is constructed indicates whether the aquifer is confined.

Where a well is to draw from a confined aquifer, the well must be cased so that water from aquifers above, which are more likely to be contaminated, cannot enter the well. All wells must be properly cased at the surface to prevent surface runoff from entering the well.

Water from an unprotected well may show no evidence of contamination in dry weather but that is no assurance of safety if surface runoff can enter the well in wet weather. Water from deep wells should be analyzed in wet and dry seasons.

Infiltration Galleries (f in Figure 7.1)

Free groundwater flowing towards streams, estuaries or lakes from upland sources can be intercepted by infiltration galleries, which are perforated pipes laid at right angles to the direction of flow. They are similar to shallow wells but one gallery is the equivalent of a line of shallow wells so that a single pumping installation replaces a pump in each well.

Infiltration galleries are useful in wetlands near coastal areas where the deeper waters are saline and the gallery can pick up the surficial fresh water.

When galleries are constructed along a stream they should preferably be at an elevation above that of the stream, so that only underground water enters the gallery. On the other hand, if the underground source is not adequate, they can be built at a lower elevation to draw from both underground sources and streams. In this instance, the quality will be influenced by water quality in the stream which may be poorer than the groundwater. However, the stream water is improved in quality as it flows through the soil to the gallery. In fact, infiltration galleries are often used as river intakes to provide water of higher quality.

Shallow Wells (h in Figure 7.1)

Shallow wells are the most widely used sources of groundwater because their adequacy is most easily determined and they are most economical to construct. Also, they can be fitted with hand pumps where piped supplies are not economically feasible.

However, because their aquifers are shallow and close to the ground surface shallow wells often suffer from deficiencies in both quantity and quality. Shallow wells are more likely to run dry in dry weather than other groundwater sources.

Accordingly, the yields of shallow wells and their water quality must be determined on wells in the vicinity before a major investment is made. The yield and quality in dry weather is particularly important because the extent of the aquifer is likely to be extremely limited. Long-term experience with wells in the area provides the most valuable information.

Yields of Groundwater

The yield of an aquifer depends on: (a) the recharge it gets through rain, melting snow and ice, or through infiltration from surface water sources such as rivers, swamps, or manmade charging basins (c in Figure 7.1); (b) the volume of water stored within the water-bearing soil or rock formation measured by its porosity, thickness and extent; (c) the rate at which the water moves through the ground and can be withdrawn from it, which is a function of its permeability and available hydraulic gradients; and (d) the amount of water lost from the ground by springs and underground discharge into rivers and lakes.

Permeability measures how well water can flow through soil or rock. It depends on the porosity and the structure of soil or rock. Porosity is the ratio of pore or void volume to the total volume. It indicates how much water can be stored in a soil layer or rock formation. Good aquifers such as gravel and sand have a porosity as high as 45%. However, even when a ground formation is highly porous, the permeability may be very low because the voids are not interconnected or the water is retained in the surface of very small particles as encountered in silt or clay.

The available hydraulic gradient is the slope of the groundwater table (in the direction of flow). The hydraulic gradient varies as the level of the groundwater table changes due to recharge or discharge. In most geological formations the rate of groundwater movement and the slope of the groundwater table are not large. In aquifers of high yield, the groundwater will move 1 to 20 m per day, assuming a slope of water table of 2 to 5 m/km. Table 7-1 shows the size, porosity and hydraulic permeability for some common soil materials.

Table 7-1 Porosity and Permeability of Aquifer Materials

Material	Size, mm	Porosity, %	Permeability mm/sec (at unit hydraulic gradient)
Unconsolidated			
clay	<0.001	45 - 55	10^{-6} to 10^{-8}
silt	0.01 to 0.001	40 - 50	10^{-2} to 10^{-6}
sand	1 to 0.01	35 - 40	10 to 10^{-2}
gravel	1 - 2	40 - 45	10^{3} to 10
Consolidated			
sandstone			
- pores		10 - 20	10^{-4} to 10^{-6}
- fissures		---	10^{-1}
limestone			
- pores		1 - 10	10^{-6} to 10^{-8}
- fissures		---	10^{2}
granite			
- pores		1	10^{-10}
- fissures		---	10^{2}

The velocity (u) in an aquifer is estimated by Darcy's law:

$$u = 0.086\ ks$$

where
u = velocity of flow [m/day]
k = hydr. permeability coeff. (see Table 7-1) [mm/sec]
s = hydr. gradient (slope of water table) [m/km]

The discharge (Q) through a cross section (A) of an aquifer is:

$$Q = uA$$

where
Q = flow [m^3/day]
A = cross section of aquifer (thickness x width) [m^2]

Example. Estimate the velocity (u) and the flow (Q) through a good aquifer (gravel and sand) with a permeability of 10 mm/sec, 50 m wide and 10 m thick, when the slope of the groundwater is 2 m per km.

$$u = 0.086 \times 10 \times 2 = 1.7 \text{ m/day}$$

$$Q = 1.7 \times 50 \times 10 = 850 \text{ m}^3\text{/day}$$

Such calculations are useful in comparing the potential yields of groundwater sources near a community, so that the most promising sources can be selected for initial exploration. However, some knowledge of the aquifer is necessary.

The maximum withdrawal that can be obtained from a groundwater source without lowering the groundwater table over time is called the safe yield. Basically no more water can be withdrawn than is recharged. Other limitations may be the maximum seasonal permissible lowering of the groundwater table to avoid a major reduction of the yield of existing wells nearby. Information about the safe yield may be obtained by observing existing wells nearby or by test wells, which should be monitored during a period of several months which includes the driest months with the lowest recharge.

A most important consideration in developing groundwater sources is that abstractions over time should not exceed recharge. Aquifers are excellent reservoirs that behave like impounding reservoirs on streams in that they can store water that accumulates during wet seasons to permit withdrawal during dry seasons. However, if withdrawals over time exceed recharge, the water levels gradually fall, requiring deeper and deeper wells and pumps, the land may subside, and the source will eventually be lost, or "mined-out". Accordingly, well operations need to be followed to be certain that, over the years, the water level in the aquifer does not continue to fall.

A distinction needs to be made between the yield of a well and the yield of a groundwater aquifer. The yield of a well is a function of the diameter of the well, the screen openings, the permeability of the soil in the vicinity of the well, and the water table drawn down to a steady state. The yield of the well depends upon the construction and location of the well. The yield of an aquifer depends upon its recharge, extent and permeability. The yield of a well or a field of wells should not be allowed to exceed the long-term yield of the aquifer or the aquifer will gradually become exhausted.

Groundwater Prospecting

Prospecting for groundwater requires highly specialized skills, hydrogeological data, and considerable time. The difficulties can be partially overcome by profiting from experience with nearby groundwater installations. Every new well is a new source of hydrogeological data.

Clays and silts have high porosity but their impermeability makes them poor aquifers. The best aquifers are sand and gravel, with sand and mixtures of sand and gravel being best as they provide some purification as water passes through them.

Rock such as sandstone, limestone, and granite are poor aquifers unless they are fissured, in which case they are excellent transmitters of water although they may not serve as good underground reservoirs. Also, passage through fissured rock offers no water purification. Limestone is noteworthy in transmitting contaminated groundwater over long distances without effecting any water quality improvement. Also, limestone waters are quite hard.

Granite produces soft water, while the other materials produce mineralization related to their chemical structure.

Finding the right location for a well is usually the job of a hydrologist, who has special knowledge of the hydrogeological condition of the local area. These experts should always be consulted for large scale ground water development in a certain area. For small rural supply systems, however, a feasible well location may be found by observing one of the following principles:

(1) Groundwater tends to flow in low lying areas. The central area of a valley, the river plains, or areas of the outlet of a small side-valley are therefore normally good places to search for groundwater.

(2) Old routes of rivers are normally very permeable and may contain groundwater even if the riverbed is dry.

(3) In mountainous areas with limestone rock, groundwater is normally found in faults and fractured zones.

Shallow aquifers may be perched water tables only, or aquifers without much extension, with little storage capacity and highly dependent on local recharge. Therefore the water table and the yield from such aquifers may be strongly influenced by seasonal variations in recharge. In some areas there is a strong correlation between streamflow and groundwater levels. Deeper aquifers may get their recharge from much larger areas and may have a quite high storage capacity.

Potential for Enlargement

An important advantage of a well supply is its potential for gradual development or staging of the supply, which is much less feasible for surface water developments. Additional wells can be added as needed, based upon experience with the initial well.

7.4 Surface Sources

Surface sources should only be considered after possible groundwater sources have been explored. Surface sources are generally more certain in their yield, but they almost always require treatment. However, they are preferred where groundwaters are saline or high in fluorides. Surface water sources in general order of preference with regard to quality are: upland streams, lakes, rivers, estuaries.

Upland Streams

Upland streams offer the best potential for surface supplies. Because their watersheds are small, they are least likely to be polluted and are most easily protected. If the watersheds are forested and the waters do not become turbid in wet weather, they may not need any other treatment than disinfection. If there is some low level of turbidity or color, direct filtration may suffice. Upland supplies also offer the potential for gravity supplies.

Because the watersheds are small, dry weather flows may be inadequate to provide water demands for the maximum day so impoundment may be necessary to provide seasonal storage. In the absence of hydrologic data, storage amounting to about a six-month supply at average demand, plus allowances for siltation, evaporation, and a conservation pool is necessary. It may also be necessary to make an allowance for releases downstream during dry weather periods.

An upland impoundment can be the basis of a hiking, boating, fishing, and picnicking area. However, if the water quality is to be maintained, strict regulations are necessary to control access and prevent despoliation of the watershed.

The design of dams and spillways for impoundments requires considerable expertise in hydrology, foundation engineering, and structures. Experts should be consulted for site selection and design of such structures.

Despite the isolation of an upland source, a sanitary survey and quality determinations in wet and dry seasons are necessary to provide a basis for watershed control activities and water treatment.

Lakes

Nearby lakes can be excellent sources of water. If located at high elevation they can provide gravity flow. Their main disadvantage is the potential for impaired quality as a result of activities on the watershed and on the lake itself. If the lake is in close proximity to habitations, it probably is subject to pollution from human and animal wastes, agricultural runoff, and other activities. Accordingly a sanitary survey is essential, together with water quality analyses at various points in the lake. An understanding of lake currents and the effects of thermal stratification and destratification is important in determining the usefulness of the lake for water supply, and the location and design of the intake. Lake sediments are also important in providing a clue to past pollution of the lakes and because the sediments may affect water quality.

Lakes subject to pollution may present more problems than rivers, because rivers tend to cleanse themselves when the pollution is abated. Lakes, on the other hand, may require long periods of time to overcome the effects of polluting discharges. Limnological expertise may be helpful in determining the long-term suitability of a lake supply.

Agricultural, industrial and shipping activities on large lakes may make them unsuitable for small water supplies, because control of these activities will not be warranted to protect a small water supply.

> **Note:** The local manual should indicate the agency responsible to supervise and regulate the competitive uses of rivers and lakes.

Rivers

Rivers offer convenient sources of supply for small communities, because they are almost always large enough. However, they are often the least appropriate because river waters are of poorest quality and a small community is not in a position to exert much control of upstream pollution. Also, intakes on large rivers are likely to be costly and pumping costs will also be great as rivers are at relatively low elevation.

Before considering a river supply, other options should be explored. Then water quality data, if any exist, should be obtained from the appropriate authorities. It is not likely to be feasible for the small community to undertake its own river quality studies.

Water quality problems are likely to be easily identified because larger cities will be using the river as a source of water supply and will have quality data and experience in treating the water. Because the technology of treatment may be a problem, it may be appropriate where a river water is the only option to consider taking water from a larger community nearby.

7.5 Conjunctive Use

In special circumstances, where a single source is not expected to be adequate the year around, consideration should be given to using two sources conjunctively. The most promising approach is the conjunctive use of surface and groundwater. In general, streams tend to dry up during summer or other dry weather periods, although they may be entirely adequate during other seasons of the year. If it is not feasible to build an impounding reservoir to provide seasonal storage, a groundwater source may be used during dry weather. During wet weather, water is drawn from the stream and the groundwater aquifer is allowed to recharge. The aquifer provides for seasonal storage.

7.6 Regional Supply

Water supply projects exhibit significant economies of scale. If a water source is adequate, developing it for twice or three times the capacity reduces the unit cost substantially. Hence two, three or more communities developing a source together may provide significant economies for each of them. Joint enterprise of several communities developing a common source may make it economically feasible to develop a higher quality source, for example, a source at a greater distance, than would be feasible for each community separately. Depending upon local circumstances, such as the geographical layout of the communities and the topography, it may be feasible to build a common treatment facility and to operate the water supply systems for the several communities as a single entity. Such regionalization will produce additional economies as well as great operating effectiveness as it may be feasible to employ more highly qualified personnel for a large system than for a small system.

Another option is for a rural community to take water from a nearby community that has developed a source and facilities larger than it needs. Such an approach may be economically attractive to both communities. The smaller community may get its supply at much lower construction cost while the larger community can reap income from its investment in resources that are otherwise not being used.

7.7 Selection from among the Options

In many instances, several source options are feasible and a selection needs to be made. The selection should be based on the least "present-worth" cost. Operating and maintenance costs are converted to present worth as described in Chapter 15. Included in the present worth estimates are the following items where appropriate:

Capital Construction Cost

- Land
- Dam and spillway
- Intake structure
- Pump house
- Pumps and motors
- Electricity source
- Standby power source
- Transmission mains
- Treatment plant
- Engineering
- Interest during construction

Operating and Maintenance Cost

- Electricity and/or fuel for raw water pumping
- Electricity for treatment
- Labor costs for intake, raw water pumping, treatment and monitoring
- Chemicals for treatment
- Labor and materials for maintenance and repairs
- Personnel for management

Where two promising options are substantially different, one with high capital cost and low operating cost, the other with low capital cost and high operating cost, cost optimization is affected by the discount rate and years of life selected for the project. Because of the almost arbitrary nature of the selection of rate and years, great precision is not warranted, and selection should not be based on cost alone if differences are only 10 to 20%.

If costs are much the same order of magnitude, the selection should be based on two less quantifiable characteristics:

(1) Quality of the source. The source of highest quality should be selected if feasible. Treatment can provide water that meets the standards, but the standards do not now include all the contaminants of concern, nor does meeting the numerical values in the standards assure safety. Inasmuch as a source will serve for many years, it is preferable to avoid possible problems than hope to solve them by treatment.

(2) Security of the supply. Some sources are more vulnerable than others. Floods, power failures, earthquakes, accidental pollution may pose greater problems for some sources than others. A gravity source is more reliable than one that depends on electrical power.

Accordingly, if present value costs are the same order of magnitude, the highest quaity and most secure source should be selected.

Chapter 8

Wells and Intakes

This chapter discusses the design of wells and intake structures, and factors which should be considered in their location and design.

8.1 The Yield of Wells

Before the yield of a well can be estimated, the potential yield of the underlying aquifer needs to be known. The yield of a well depends on the permeability and capacity of the aquifer and on the design of the well. A simple approach to estimating the yield is based on the assumption that the well withdraws water from an aquifer with an approximately horizontal water table and a steady flow to the well from all directions. The method to be used depends on whether the aquifer is unconfined, with a free watertable (Figure 8-1), or confined within two impermeable strata (Figure 8-2).

When water is drawn from a well the water table is drawn down. Figure 8-1 shows an unconfined aquifer. The difference between the level of the original water table and the final level in the well (p_o) is called drawdown. The water level decreases towards the well and forms a drawdown curve. The yield (Q) is a function of the permeability, the drawdown (P_o = H-h), the circle of influence of the well (2R), and the diameter of the well (2r). It can be expressed as:

$$Q = C \frac{K(H^2-h^2)}{\log (R/r)}$$

where
C = a dimensional constant
K = permeability (mm/sec)
H, h, R, and r are shown in Figure 8-1.

Because H (the water level) and K (the permeability) can be estimated, the drawdown (p_o) which determines h is the most important factor. The diameter of the well (2r) does not greatly influence the yield, because the yield is only increased by the logarithm of its value. For example, if the well diameter is increased from 50 mm to 300 mm, the yield is only increased by about 15 to 30% depending on R (the radius of influence). Based upon the yield of an existing well in the vicinity, and the parameters indicated, the relative yield of proposed wells can be estimated for various designs.

The same theory applies to the yield of an artesian well in a confined aquifer (Figure 8-2). The yield (Q) in this case is a function of the permeability, the thickness of the aquifer (m), the drawdown (p_o), the circle of influence (2R), and the diameter of the well (2r). The permeability, the drawdown, and the thickness of the aquifer are of equal importance while the well diameter has much less influence on the yield.

Two or a group of wells drawing simultaneously from the same aquifer may increase the drawdown of each well if they are placed close together. The drawdown at any point in the area is approximately equal to the sum of the drawdowns caused by each well individually. Because the drawdown has a major impact on the yield, the distance between wells must be adequate to avoid

Figure 8-1 Watertable Well in a Groundwater Reservoir

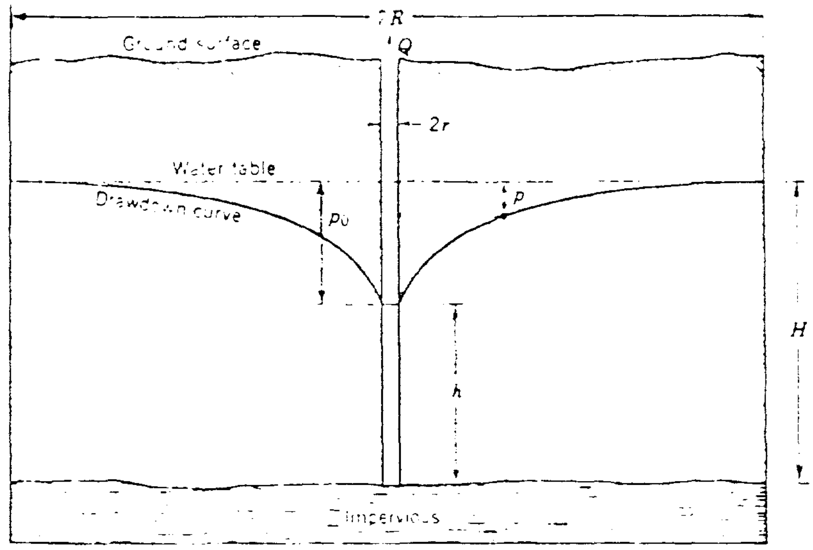
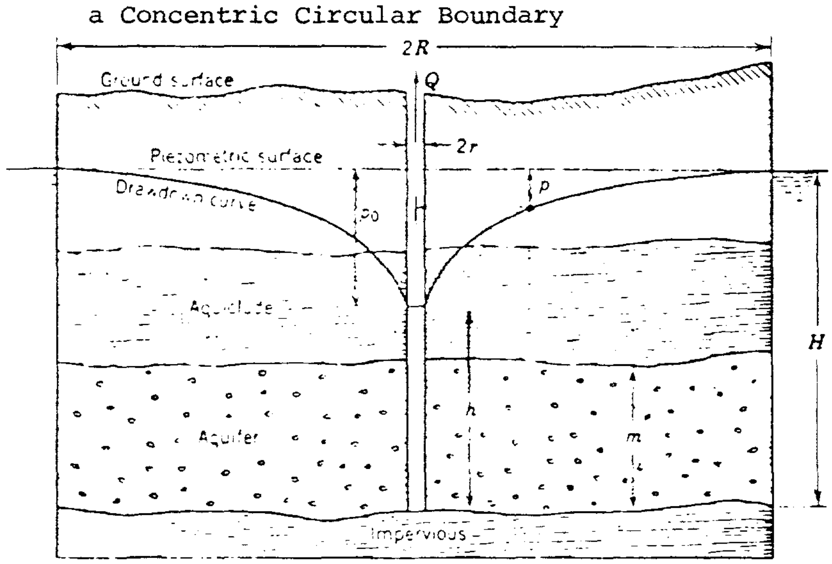


Figure 8-2 Artesian Well with Steady Radial Flow from a Concentric Circular Boundary



Source: Fair, Geyer, Okun (1966)

interference. The use of two wells is desirable so that one would serve as standby.

The yield and the drawdown are influenced by: (1) the length of the intake or screen section (Figure 8-3), if it does not penetrate the full depth of the aquifer; (2) the friction caused by the intake or screen, called well losses; (3) the slope of the water table (Figure 8-4); and (4) impermeable boundaries near the well.

The importance of these factors varies considerably depending on local conditions. A hydrologist may need to be consulted to evaluate these factors if experience with wells in the vicinity does not provide enough guidance.

8.2 Types of Wells

Wells are generally classified according to their method of construction. For rural water supplies wells are hand dug, driven, jetted, bored, or drilled wells. Selection depends on the depth of the aquifer, soil type, and the construction equipment and financial resources available. All wells have four basic parts as shown in Figure 8-5: casing, intake area, well head and water-lifting device.

Hand-dug Wells

The construction of dug wells (Figure 8-6) requires neither special equipment nor special skills. Hand dug wells are usually 1 to 1.3 m in diameter and rarely more than 10 m deep.

The casing can be made with brick, stone, masonry or concrete. If concrete casing is used it may either be precast and be sunk in the well (Figure 8-7) or poured in form work inside the well (Figure 8-8). The yield of a dug well depends mainly on the permeability of the aquifer and the well depth below the water table. Depending on soil conditions it may vary from 5 to 200 m^3/day but may reach more in very permeable soils. Enlargement of the diameter only increases the yield slightly (doubling the diameter increases the yield less than 10%) but does provide storage.

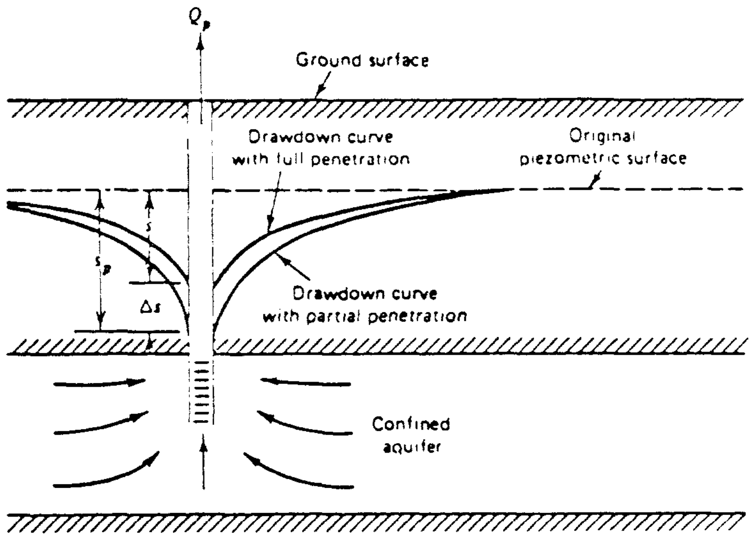
In fine grained sand the bottom of the well is covered with several layers of graded gravel (Figure 8-9). In coarse granular material, the casing should have openings to allow the water to enter the well, but which are small enough to prevent the surrounding material from passing into the well.

To protect against contamination, the well must be completely sealed, and the walls of the well should be at least 0.2 m above ground level. Space between the wall casing and the well should be filled with gravel to the top of the aquifer and the upper part sealed with cement grouting (Figure 8-10). The water should be chlorinated for disinfection after the well has been completed and repeated at regular intervals if it is not chlorinated continuously. Dug well construction allows the combination of several materials and construction methods (Figure 8-11).

Driven Wells

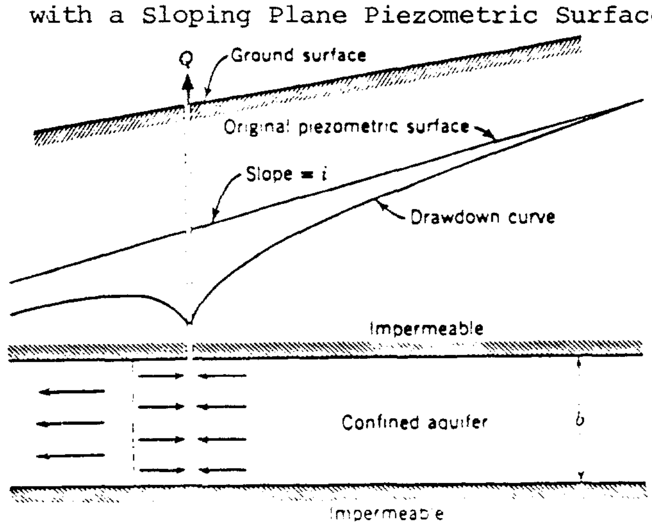
Driven wells are built by driving a "well point" (Figure 8-12) into the ground until it reaches the water bearing formation. The well point should have a slightly larger diameter than the screen and must be made of hard high quality steel to prevent damage when driving through pebbles or thin layers of

Figure 8-3 Partially Penetrating Well in a Confined Aquifer



Source: Todd (1980)

Figure 8-4 Flow to a Well Penetrating a Confined Aquifer
with a Sloping Plane Piezometric Surface



Source: Todd (1980)

Figure 8-5 Parts of a Well

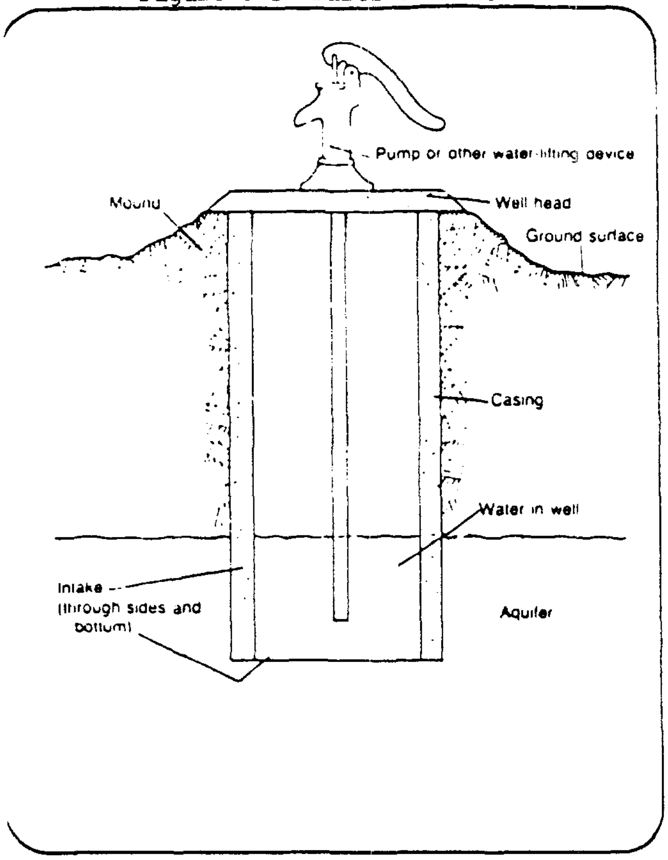
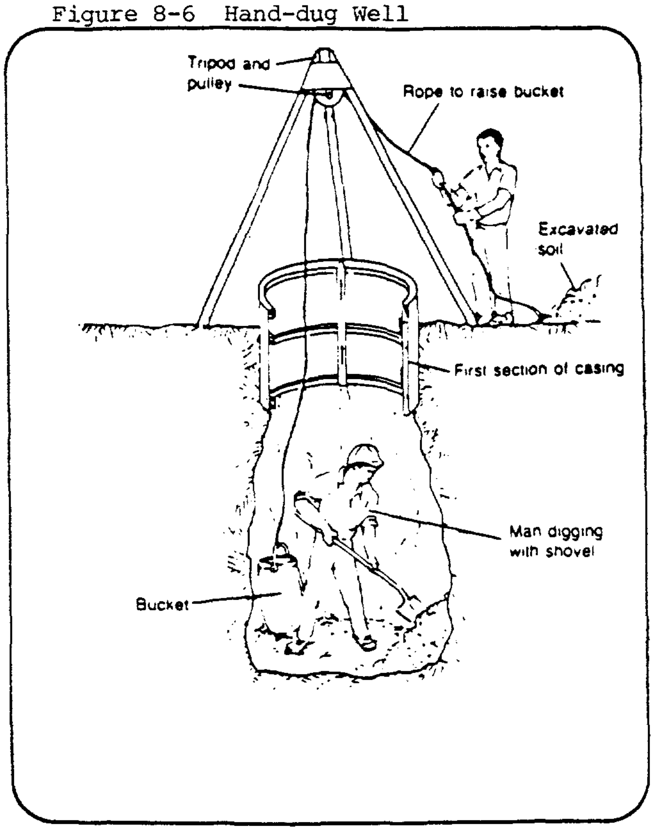


Figure 8-6 Hand-dug Well



Source: : Water for the World (1982)

Figure 8-7 Sinking a Dug Well by Excavation from the Inside

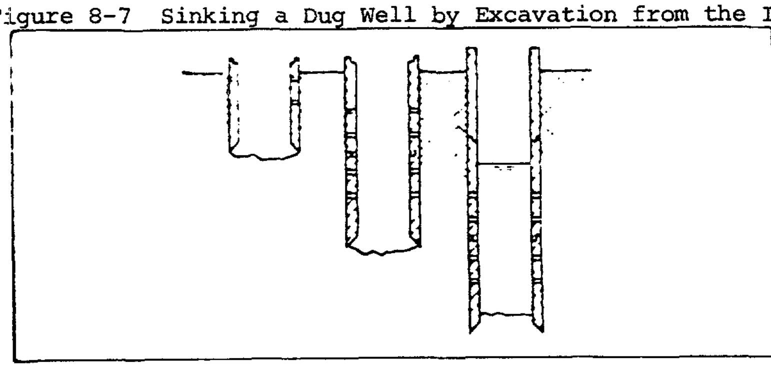
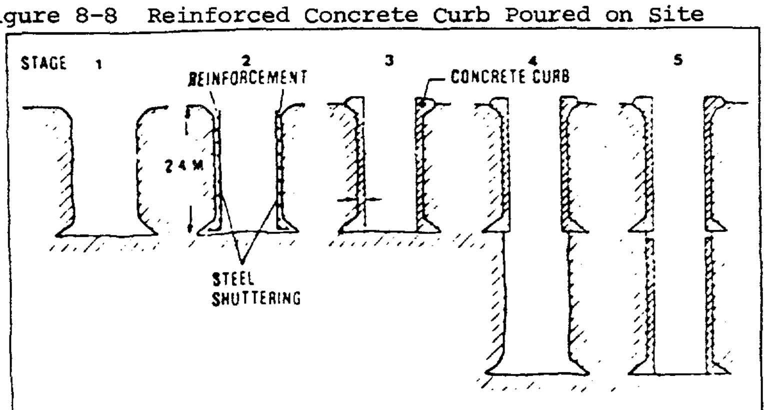


Figure 8-8 Reinforced Concrete Curb Poured on Site



Source: Hofkes (1981)

Figure 8-9 Dug Well in Fine Granular Aquifer

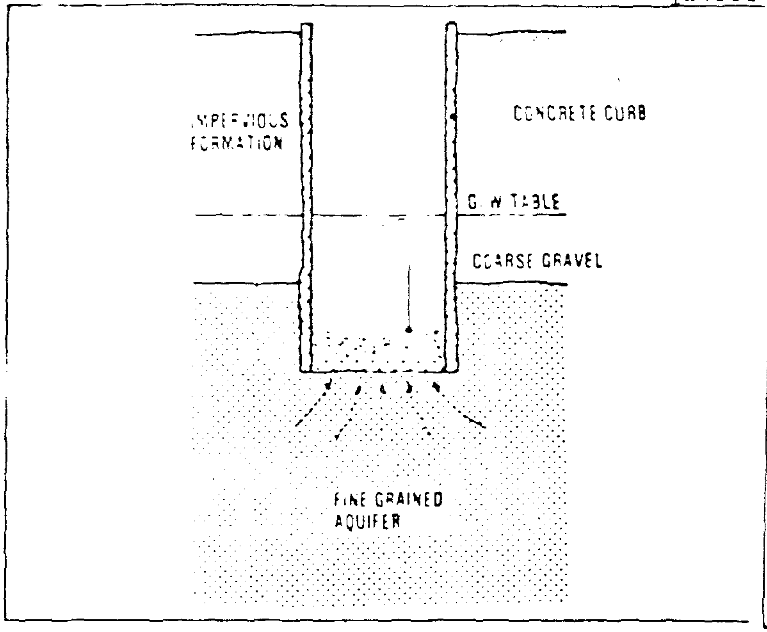


Figure 8-10 Dug Well Construction with Pre-fabricated Rings

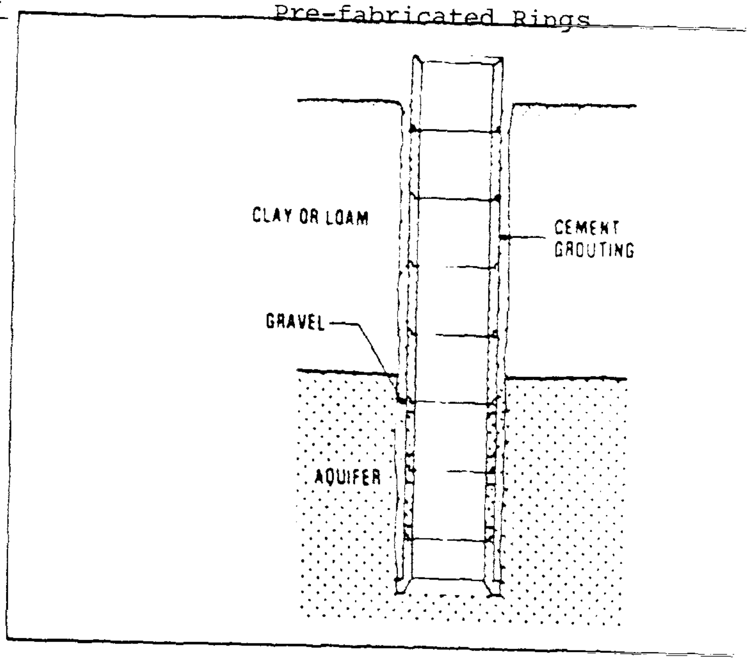
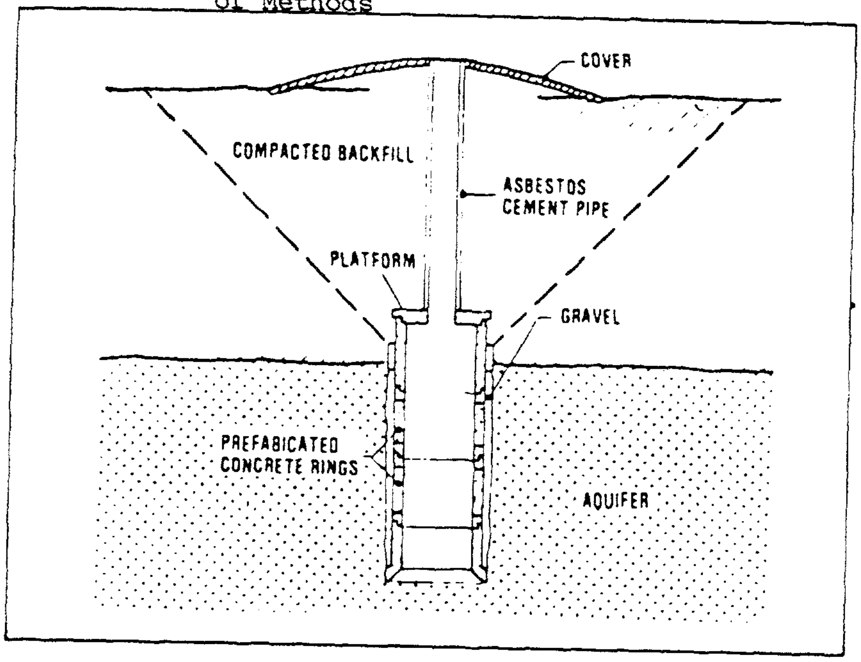


Figure 8-11 Dug Well Construction Using Comgination of Methods



Source: Hofkes (1981)

Source: Hofkes (1981)

rock. The feasible diameter ranges from 30 to 50 mm and may reach a maximum of about 100 mm in soft soils. The depth is limited to less than 10 to 15 m, as the resistance against driving increases with depth. This method is limited to shallow aquifers (maximum depth of water table about 9m), because submerged pumps cannot be installed inside such small diameter wells.

Driven wells are especially suitable in soft sandy formations, but are inappropriate in hard rock formations and areas where many boulders or other hard obstacles are encountered in the ground.

In clay formations, the screen openings may become clogged with clay during the driving. If clay is encountered just below the surface, a combination of boring (see next section) and driving may be feasible.

The yield from driven wells is normally 5 to 100 m^3/day, but may be more in very permeable soils.

Two basic methods are employed to drive the well point: (a) the driving force (hammer or sliding weight) is transmitted over the casing, which then must be strong and thick walled (Figure 8-12); or (b) the well point is driven by a drive bar inside the casing (Figure 8-13), with the casing being pulled into the ground rather than driven.

Jetted Wells

Jetted wells are constructed by the erosive action of a stream of water jetting from the well point (Figure 8-14). Plastic pipe may be used for the casing because no mechanical force is needed to drive it. A pump with a capacity of approximately 500 l/min at a pressure of 3 to 5 atmospheres is required to produce the jetting stream. The rate of sinking the well may be improved with the simultaneous use of a rotary drill bit.

The application of jetting is limited to unconsolidated soil formations without large boulders. Compared to driven wells, jetting of wells is very fast and greater depths, up to 50 m or more, may be reached. There is also no risk of clogging the well screen. The diameter of the jetting pipe ranges from 30 to 50 mm, but larger jetting pipes may be used.

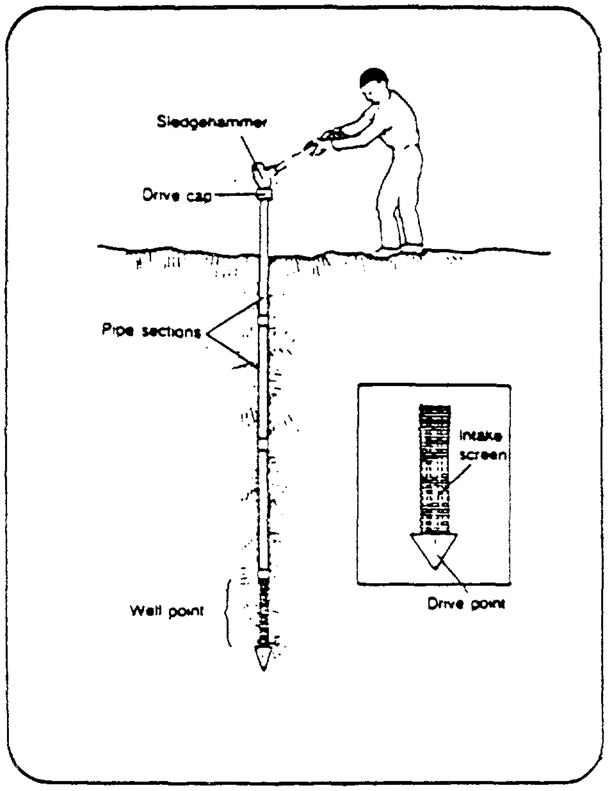
The yield of jetted wells has about the same range as driven wells (5 to 100 m^3/day). However, in certain soils, jetted wells may be sunk very deep in the aquifer, and produce larger yields. With a sufficiently large casing, deep aquifers may be used by installing submerged pumps.

Bored Wells

Bored wells can be constructed with simple hand operated equipment in soft ground with shallow groundwater levels; otherwise mechanical powered equipment is required.

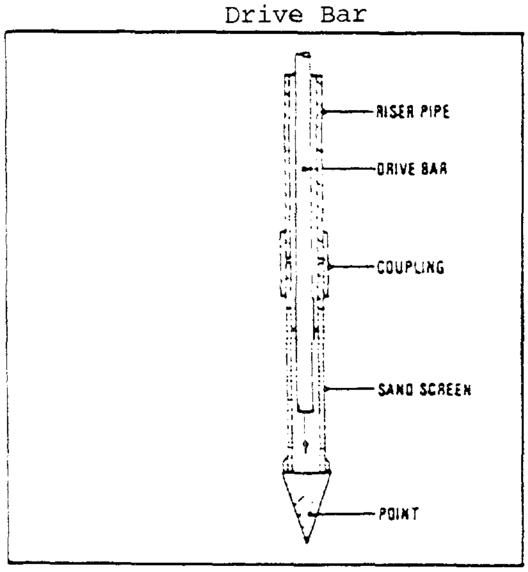
Hand drilled wells are dug by manually rotating an earth auger which penetrates the ground (Figure 8-15). From time to time the auger is raised out of the hole together with the soil excavated. The method is used in drilling to depths of about 15 m in clay, silt and sand formations. Several accessories have been developed to facilitate drilling through different types of soils.

Figure 8-12 Driven Well



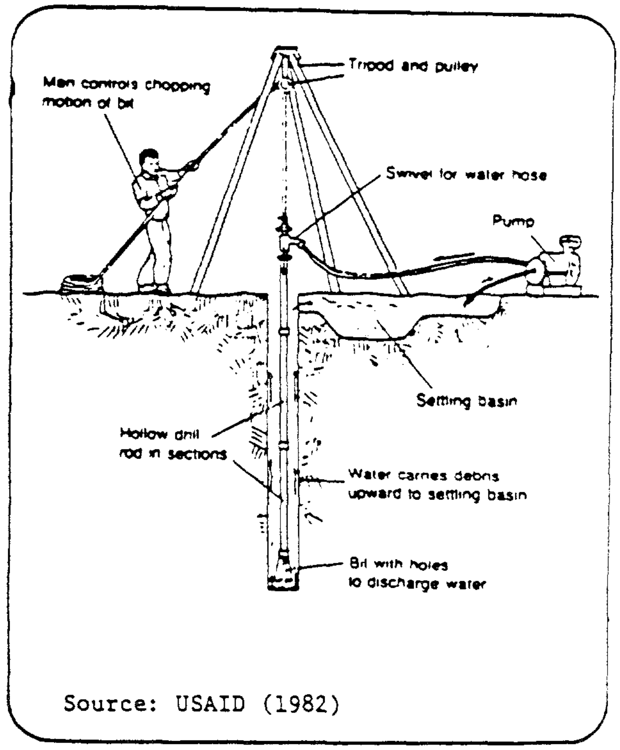
Source: USAID (1982)

Figure 8-13 Well driving with Inside Drive Bar



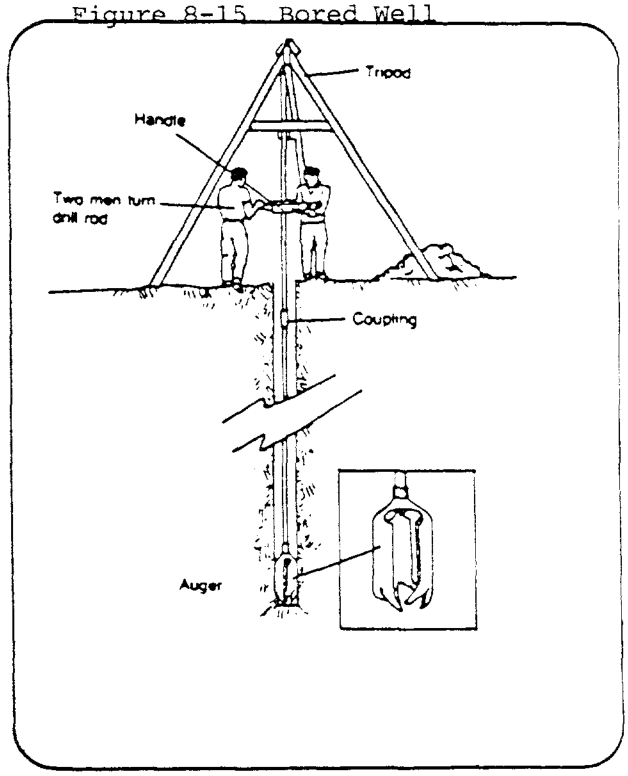
Source: Hofkes (1981)

Figure 8-14 Jetted Well



Source: USAID (1982)

Figure 8-15 Bored Well



Source: USAID (1982)

The diameter of hand drilled wells may reach 200 mm or more, permitting the installation of submerged pumps. Several types of casing (iron, plastic or asbestos pipes) can be used. The yield of hand drilled wells ranges from 5 to several hundred m^3 per day.

With engine powered augers, wells of large diameters (300 mm and more) may be constructed and greater depths can be reached. For wells deeper than 20 to 30 m, one of the drilling methods in the following section should be considered.

Drilled Wells

The term "drilled wells" is normally used to describe methods using engine powered mechanical drilling rigs. Two methods are generally used: the cable-tool (or percussion) method and the rotary method.

The cable-tool method is one of the oldest methods used in well construction. It employs the principle of a free falling heavy bit delivering blows against the bottom of the well hole forcing its way into the ground. The loose ground is mixed with water and periodically removed by sand pumps or bailers.

The cable-tool method can be used to drill in a wide range of ground formations. In particular this method can be used to drill through boulders and soft or fractured rock formations. Depending on the equipment and ground condition, wells of up to 600 mm diameter may be constructed to a depth of up to 100 m. The yield of cable-tool wells varies from below one hundred to several thousand m^3 per day in deep, highly permeable aquifers.

The rotary drilling method uses a rotating bit for cutting the borehole. The cut material is continuously removed by a circulating mixture of water and clay or other additives, which are pumped into the well. The clay seals the well walls, preventing collapse of the borehole.

Rotary drilling may be employed in any soil or rock formation, and at rapid drilling rates, but the equipment and construction costs are high.

Gravel-packed Wells

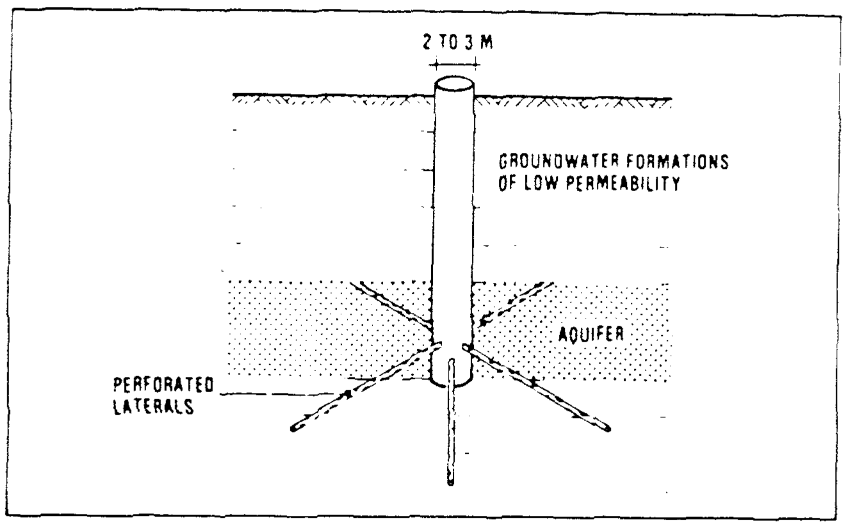
An envelope of gravel placed outside the well screen forms a filter that keeps sand out of the well and effectively enlarges the hydraulic diameter of the well. This filter reduces the friction losses of the water entering the well resulting in a smaller drawdown.

The well hole should be at least 20 cm greater than the inner well-screen diameter. Often an outer casing is used to support the borehole. Gravel that occupies the opening between the two casings should be well rounded with a particle size 8 to 10 times greater than the particle sizes in the aquifer. The gravel should extend at least 0.5 to 1 m above the water bearing layer, and be sealed off with clay or cement grout to avoid pollution.

Collector Wells and Horizontal Wells

Collector wells or horizontal wells may be advantageous in thin, or poorly permeable aquifers, areas underlain by saline water, or where groundwater is derived primarily from infiltration of streams (Figure 8-16). The central shaft of the well is a concrete caisson about 2 to 3 m in diameter with a thick concrete plug at the bottom of the well. From this shaft, radial

Figure 8-16 Radial Collector Well



Source: Hofkes (1981)

collector pipes, 10 to 20 mm in diameter, extend horizontally into the aquifer or below the riverbed. The design and construction of such wells requires expertise and should be carried out by a specialist. Therefore, this type of well is generally less suited to rural water supplies.

8.3 Well Casings and Screens

The well casing serves as a lining of the well. It also seals out surface water and any undesirable groundwater. Materials commonly used for well casings singly or in combination are steel, iron, asbestos cement, brick, concrete, and plastic, depending on the construction method, the aquifer, the depth, and the financial resources available. Some construction methods use temporary casings to support the borehole during drilling and to reduce losses of drilling fluids.

Nonmetalic material should be used where corrosion or incrustation by iron bacteria is a problem. However, nonmetalic casings and screens tend to be weaker than metallic materials.

Normally the diameter of the casing is at least 5 cm larger than the diameter of the suction pipe or submerged pump installed in the well. Common diameters of wells, casings and screens are:

Well Yield (m^3/day)	Screen Diam. (mm)	Pump Chamber Casing (mm)	Gravel Packed Wells (mm)
300	50	150	450
300-700	100	200	500
700-2000	150	250	550

Note: The local manual should specify design standards and identify well casings available locally, including casings and well points for driven wells.

The well screen is designed to keep out sand while minimizing resistance to water flow. About 15% of the screen surface should be perforated. In aquifers of widely varying particle size, well capacity is improved if screen openings allow fine sand to enter the well while retaining coarse particles. A graded, permeable filter is thereby generated around the screen. Normally the slot size should be selected to retain about 30 to 50 percent of the aquifer material. The development of this natural filter can be achieved by several methods described in the next section.

8.4 Well Design, Construction, and Development

The design and construction of wells normally includes the following phases:

(1) determination of required capacity;

(2) hydrogeological information and investigation for source and site selection;

(3) selection of construction method and provisional design of well (type, diameter, casing and filter material) based on available data from nearby wells or small diameter test wells;

(4) well drilling, including careful sampling and recording of ground conditions. The drilling log should record a complete description of each soil layer encountered. Soil samples should be taken from each layer and stored for possible sieve analysis;

(5) final design: final layout of well (casing, screen, filter) based on drilling log and sieve analyses;

(6) well alignment: control of verticality or plumbness and straightness are required for the proper installation of the casing and screen and most important for wells with pumps below water and drives above ground, because deviations from the vertical affect operation and life of the pump;

(7) installation of casing, screens, pumps and motors, including gravel in gravel-packed wells.

Following completion, a new well must be developed to optimize its yield and life. Its permeability is increased by removing the fine material around the screen. The following methods are commonly used to develop wells:

(a) step and shock pumping: pumping of a well in a series of steps from a low discharge to a discharge greater than the design capacity. At each step the well is pumped until the water is free of sand and clear. Often the yield can further be improved by careful shock pumping (irregular start and stop of pump) of the well at increasing discharge rates.

(b) surging: up and down movement of a surge plunger within the well. The downstroke loosens the material near the screen, while the upstroke pulls dislodged fine material into the well. This is often done before step pumping.

(c) jetting or backwashing: a high-velocity stream of water into the well backwashes the aquifer through the screen openings. This requires a high pressure, high capacity pump.

The importance of well development is often under-estimated, so that wells are not adequately developed, and a portion of the potential yield of the well is not utilized.

> **Note:** In order to ensure adequate development of wells and optimize the investment in well construction, the availability of appropriate diesel powered, high capacity pumps and suring equipment for well development should be indicated.

After a well is developed its hydraulic characteristics must be determined by pumping tests so as to select a pump with the most appropriate characteristics to maximize the pump efficiency and minimize pumping cost. Testing requires a pump, and devices to measure the water level in the well and the discharge from the well. The test should provide the specific capacity of the well, the discharge per unit drawdown, for various discharges.

Pump Selection

The selection of pump type and characteristics (Chapter 9) depends on: (1) well capacity; (2) hydraulic characteristics of well (specific capacity, and maximum seasonal fluctuation of groundwater level); (3) required total pumping head to pump water to treatment plant, elevated storage tank or into network; (4) well diameter and depth; (5) duration of pumping cycles; (6) type of power available; and (7) costs.

A pump must discharge the design flow against the total pressure or head, both static and dynamic. As shown in Figure 8-17, the total head is a function of the well discharge depending on: (1) the discharge-drawdown curve of the well; (2) the level of the water table; (3) the elevation of the storage tank or the desired pressure in the system at its highest point; and (4) the friction losses in the system.

In shallow wells with suction lifts of less than about 7 meters (and preferably under 4 m) centrifugal pumps can be mounted on the well or on the ground near the well.

For deeper wells, pumps which can operate within the well casing have to be used. Several types of pumps are suitable for deep well operation: plunger, displacement, airlift, jet, and, most important, drive-shaft and submersible pumps. Drive-shaft pumps are driven by a power source at the surface, so that vertical alignment of the well must be precise to avoid wearing of the transmission and bearings.

Submersible pumps are driven by a submerged electric motor attached to the pump, eliminating the drive shaft. Submersibles have high efficiencies and have shown long periods of trouble-free and maintenance-free operation, so they are widely used today.

Protection of Wells

Precautions must be taken to protect well water quality. The well top should be provided with a water tight cover and the casing must be sealed off with cement grout and a concrete slab which slopes away from the well as shown in Figure 8-18. Before the well is placed in operation and after any maintenance work, the well should be disinfected with chlorine. If a well is abandoned it must be sealed with clay or concrete to protect the groundwater from contamination.

> **Note:** More detailed information on design, construction and protection of wells should be provided in a special design and construction manual, wich integrates local expertise developed on former projects.

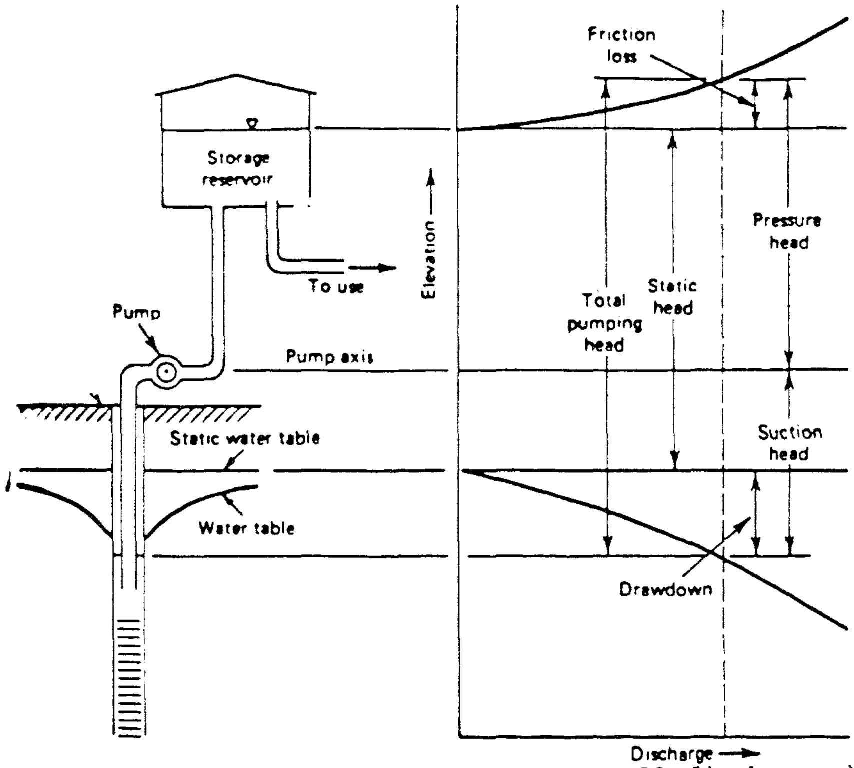
8.5 <u>Well Maintenance and Rehabilitation</u>

Wells need regular maintenance. When too little attention is paid to declining performance of a well, serious problems may result in complete loss of the well.

The most common reason for reduced well performance is the clogging of the well screens by incrusting deposits. These deposits are formed by (1) precipitation of carbonates of calcium and magnesium; (2) precipitation of oxidized iron and manganese compounds; (3) slime produced by iron bacteria; and/or (4) silt and clay.

Other problems include corrosion of well screens, cracks in concrete casings, and inadequate development of the well. These may result in sand and silt entering the well, which cause excessive wearing of the pump and pipes and reduce the performance of the pump as well as the lifetime of pump and pipes.

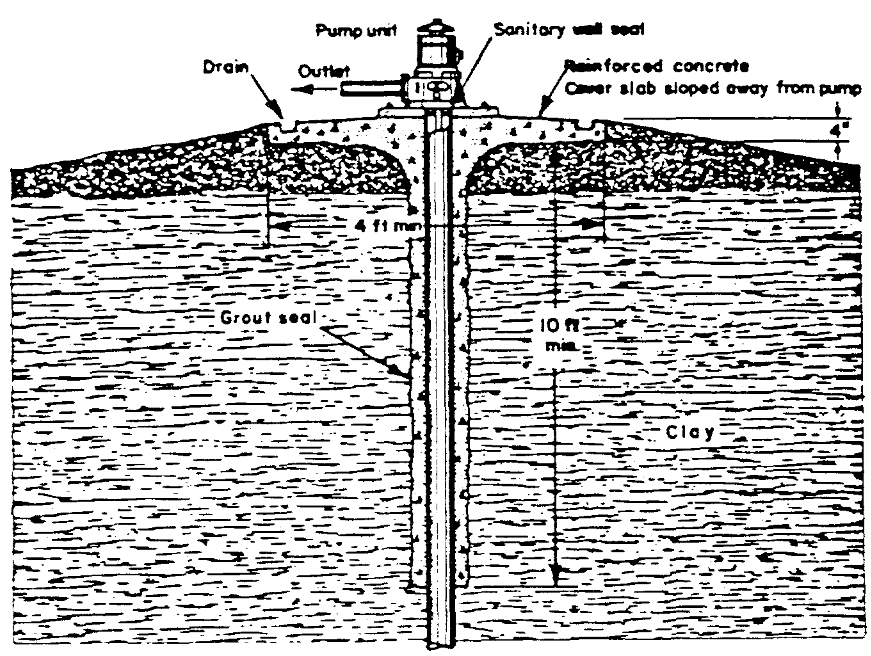
Figure 8-17 Total Pumping Head for a Well Supplying a Storage Reservoir



(Note the increase in head as a function of well discharge.)

Source: Todd (1980)

Figure 8-18 Sanitary Protection of Upper Terminal of Well



Source: USAID (1969)

To detect such problems early, records should be kept of discharge rate, drawdown, power consumption, hours of operation, and water quality. The best indicators of problems are a drop in the specific capacity (discharge rate per unit drawdown) and increased power consumption.

No methods have yet been developed for the complete prevention of well incrustation. However, timely investigation and maintenance whenever the records show any problem can reduce its effect. The following methods are commonly used :

(1) Acid Treatment. Acids, which readily dissolve calcium and magnesium, such as hydrochloric or sulfuric acids, are usually employed. To prevent serious damage to the metal or concrete screen and casing by the acid, inhibitors such as gelatin should be added.

(2) Solution of deposits by polyphosphates. These chemicals combined with a small amount of hypochlorite tend to disperse the deposits on the screen.

(3) Regular chlorination.

(4) Physical Agitation. Chemical treatment is improved by agitation of the water.

8.6 Intakes for Springs

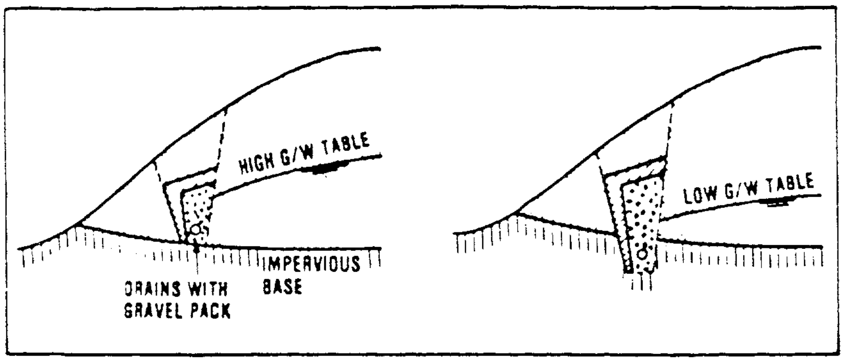
Spring intakes tap spring water and protect it from pollution. The design of the intake depends on the hydrogeological situation. Two basic types of intake structures are used: (i) infiltration galleries or collection ditches, and (ii) collection or spring boxes.

Infiltration galleries can be constructed as collection ditches consisting of perforated or open joint pipes, placed in a gravel filter (Figure 8-19) or a small perforated tunnel. The infiltration gallery extends across the entire water-bearing zone to collect the maximum amount of water. The intake should extend below the water bearing zone to permit the free flow into the collector. The gallery is connected to a collection or spring box, where the discharge can be inspected (Figure 8-20). Anti-seepage walls may have to be constructed either along the drain ditch (Figure 8-19) or attached to the collection box (Figure 8-20) to prevent water from escaping.

For sanitary protection the drains or gallery should be at least 3 m below the surface and may be sealed off against pollution. A protective zone extending over the full length of the intake plus about 10 m at each side and at least 50 to 100 m upstream should be established. This area may be extended, if the covering soil layers are quite permeable. Within this area any source of pollution should be avoided. Houses, stables, animal grazing or any other activity which may pollute the water should be banned.

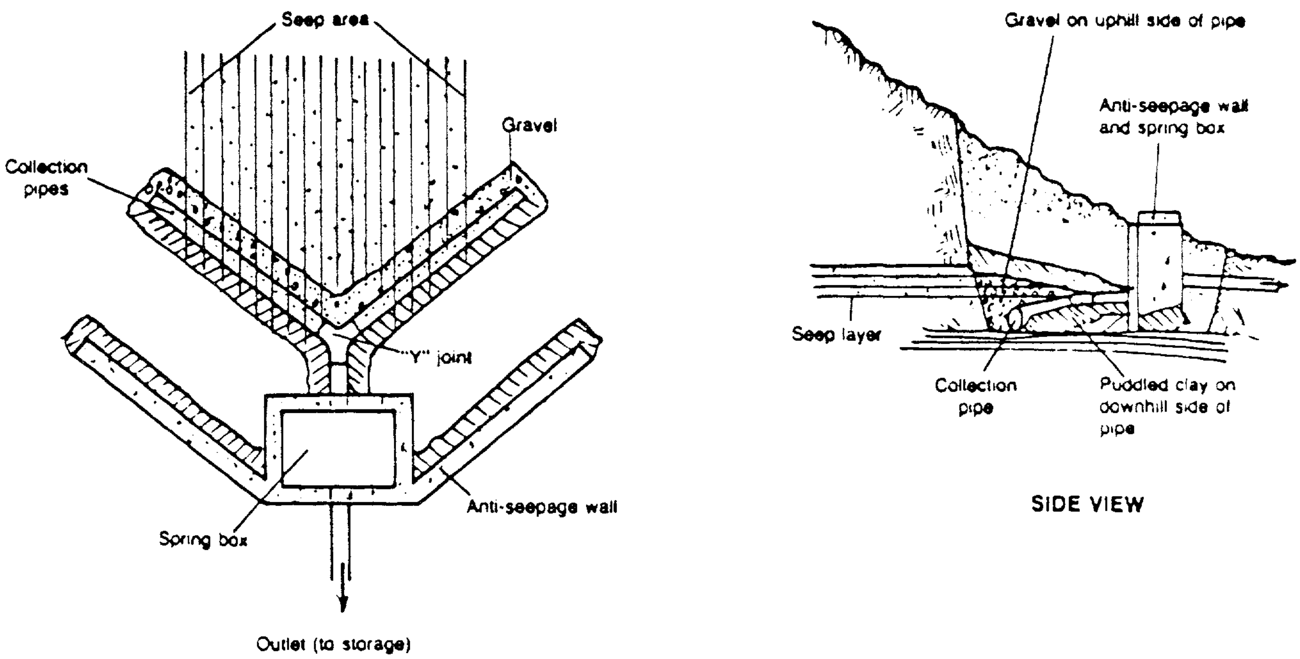
Collection or spring boxes collect the water from several pipes and allow the inspection of the water flow and quality. An overflow must be installed to discharge the inflow water whenever the supply has to be cut off. For springs that flow from one single spot a collection box or spring box with an open bottom or back can be placed directly in front of the water bearing fissure (Figure 8-21). The chamber should be built in such a way that contamination of the collected water is prevented. A diversion ditch should prevent surface runoff from reaching the chamber. Air vents, overflow pipes and clean out drains must be screened and any manhole covers should be fitted with a lock.

Figure 8-19 Tapping of a Gravity Spring



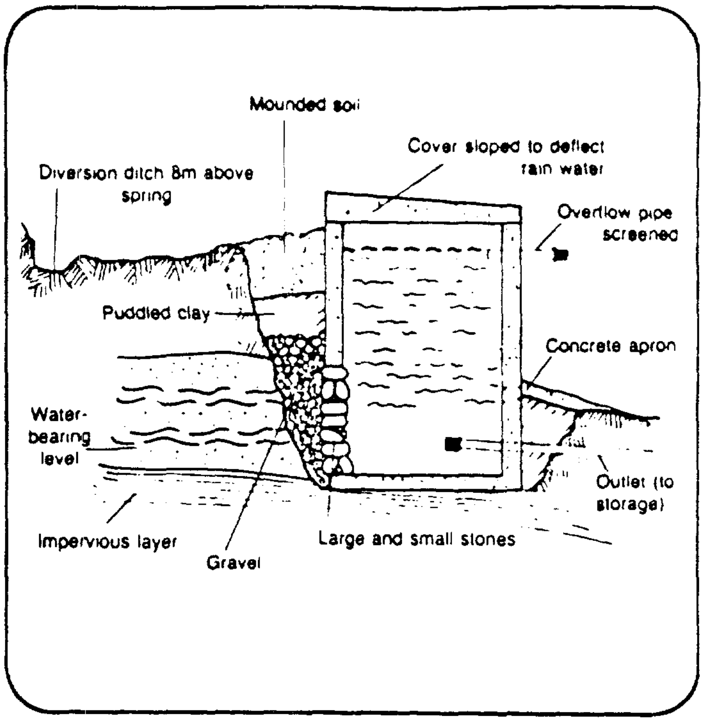
Source: Hofkes (1981)

Figure 8-20 Seepage Collection System



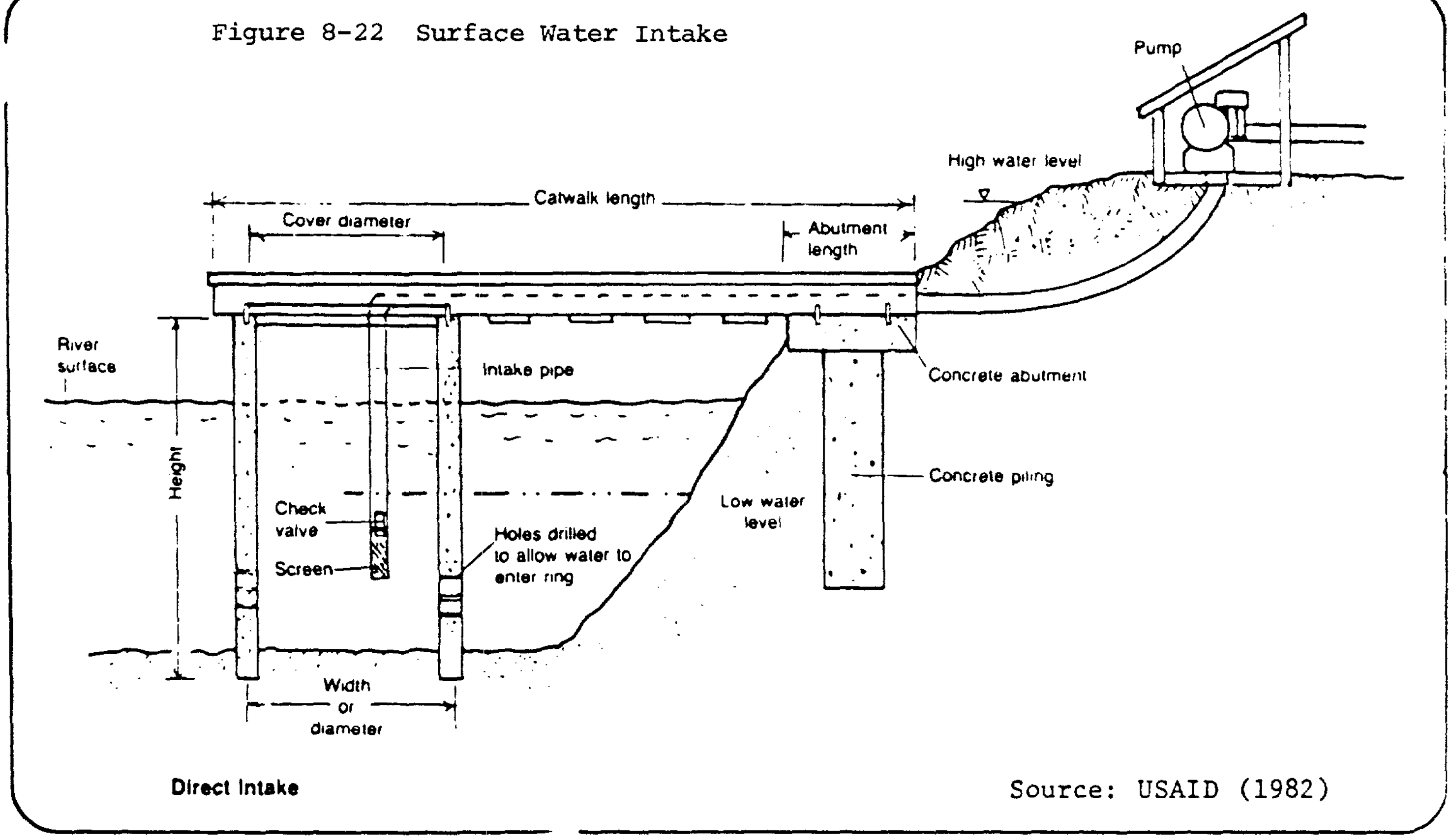
Source: USAID (1982)

Figure 8-21 Spring Box with Pervious Side



Source: USAID (1982)

Figure 8-22 Surface Water Intake



Source: USAID (1982)

If the water contains small amounts of silt or sand the collection box may be designed as a sedimentation chamber. Masonry and concrete seem to be the most suitable building materials for spring and collection boxes.

8.7 Surface Water Intakes

Intakes are required where surface waters are used. Their placement and design depend on the type of surface source.

General Design Features

The intake can be a pipe in the water, an infiltration system underground, or a tower placed in the water:

(a) An intake pipe is usually covered by a protective screen installed in a small structure to keep debris from hitting and breaking the pipe and getting into the system. The pipe opening depends upon the capacity, with suggested velocities varying from 0.5 to 1.0 m/s.

(b) An infiltration system consists of either a well next to the water source, or a perforated pipe placed either in the riverbed or next to the river. The infiltration pipe is surrounded by gravel and smaller rock, graded with the smallest material on the outside so it doesn't clog the pipe. An infiltration intake provides a better quality of water than the other surface water intake systems, because the water is collected through a natural filter.

The problem with placing a collection pipe in the river bed is that the water must be diverted during excavation. One solution is to dig a dry trench next to the pond or stream, lay the pipe, and then dig a channel or lay another pipe to bring the water from the source into the ditch. The infiltration pipe may have holes or slots in it, or have open joints.

(c) Placing a tower directly in the water permits drawing water at one of several elevations (Figure 8-22).

Table 8-1 characterizes the conditions under which each intake system can be used.

The depth at which an open pipe intake is placed is important, as water quality varies with depth. In lakes it is best to keep intakes at least 3 to 5 m below the surface, to avoid surface layers which are heated by the sun and may be rich in algae. Bottom intakes are unsatisfactory because bottom waters may have no dissolved oxygen, be high in hydrogen sulfide. Also, bottom intakes may be covered with silt. In deep lakes, intakes at various levels are desirable.

To keep an intake submerged in a river or lake that may rise and fall with the seasons, movable or variable-level intakes may be used (Figure 8-23).

River intake structures:

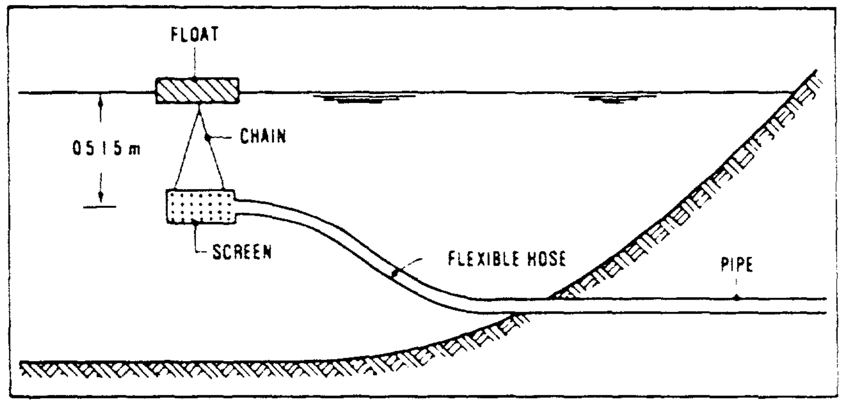
- should be located in a zone with excellent water quality;
- should have a stable bed and slope, with adequate water depth, generally in a straight reach or on the outside of a bend in the river;
- should be low in silt and sand, and algae;
- should not obstruct navigation or flood drainage and should meet requirements regarding dredging;
- should be located as near the site where the water will be used as feasible; and
- should be located upstream from residential and industrial development.

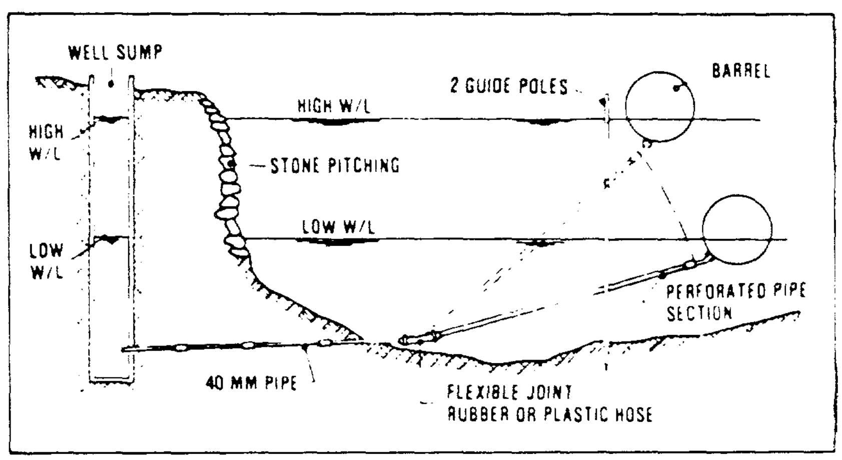
Table 8-1 Conditions for the Use of Surface Water Intake Structures

Surface Water Intake Structure	Conditions for Use
Bank Type	Suitable for use on a fairly steep river bank, where the water is quite deep, with good water quality and geological conditions, and not too great variations in water level.
Riverbed type	Suitable for use on a fairly flat river bank, where the main stream is quite far from the bank in the dry season, where water depth at the bank is inadequate or water quality poor, but the middle of the river offers sufficiently deep and good-quality water.
Trough type	Suitable for use where there is a very high sand content in the river flow, or where there is severe freezing and a large amount of water is needed.
Storage hold type	Suitable for use where river water level changes by 10-35 meters or more, and at a rate of not more than 2 meters per hour, where dry-season depth is more than 1 meter, where the flow is stable with few waves, excellent berthing conditions, stable river bed, river bank has suitable slope (generally 20°-30°), no freezing, few floating materials, not subject driftwood, flotsam or jetsam.
Cable car type	Suitable for use where river water depth varies between 10-35 meters and speed of variation is greater than 2 meters, river bed is fairly stable, bank geological conditions are quite good, bank slope is suitable (generally between 10°-30°), river is straight and bank is near main stream, little floating material, no freezing, not subject to driftwood, flotsam or jetsam.
Bottom slab type	Suitable for use in mountainous regions with inadequate river sources, or when the amount of water needed accounts for too much of the dry-season flow (over 30-50%), where bed load is not too great.
Bottom grid type	Suitable for use where water is shallow and bed load is heavier in mountainous region rivers, where the amount of water needed is 30-50% of the dry-season flow.

Source: PRC Manual (1982)

Figure 8-23 Float Intakes





Source: Hofkes (1981)

Pump Selection

In most cases, pumping will be required to raise the water to the system. Suction pumps work well for lifts of 3.5 to 4 m (Figure 8-24). Pumps should preferably be placed below water elevation to assure positive suction. It can be placed in the collection well of an infiltration system (see Figure 8-25), in a dry well or wet well near the source, or in a tower built in the river.

Figure 8-24 Pumped River Water Intake

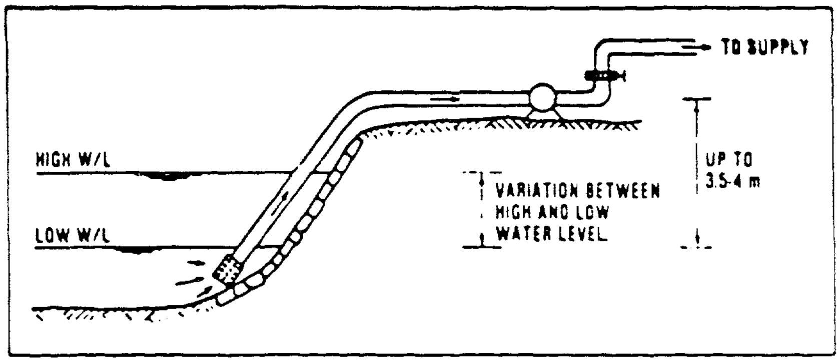
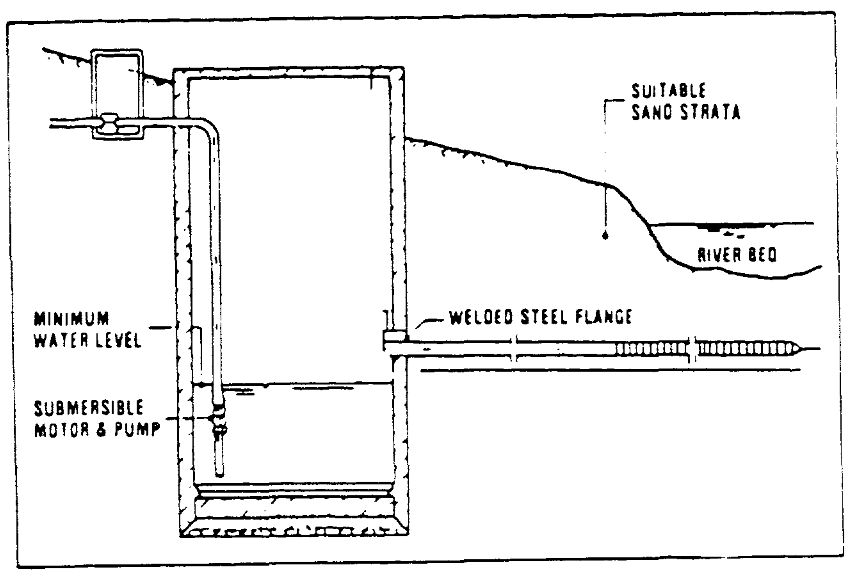


Figure 8-25 Bank River Intake Using Infiltration Drains



Source: Hofkes (1981)

Chapter 9

Pumps

Many types and sizes of pumps, driven by a variety of power sources, are available. The most commonly used pumps in rural water supply systems are hand pumps, turbine and centrifugal pumps which are available in submersible designs, and displacement pumps. Other types of pumps with limited application are air lift pumps and hydraulic rams. Each type and size of pump has a typical characteristic curve which shows the pumping head for varying discharges, and the associated efficiencies (Figure 9-1). The total pumping head (H) is equal to the static lift (H_s) plus the friction losses (H) caused in the suction and transmission pipes by the water flow (Figure 9-2). (The calculation of friction losses is discussed in Chapter 10.)

If the discharge is expected to vary considerably, a pump with a flat characteristic curve is chosen. If the discharge is to be relatively constant but the head may vary, pumps with a steep characteristic curve should be considered.

9.1 Types of Pumps

Hand Pumps

Hand pumps are most commonly used for shallow or small-diameter wells which supply up to about 200 people. For very shallow wells (required maximum lift about 7 m but preferably less than 4 m), suction pumps (Figure 9-3) may be used. Many different types are available. The suction pump uses atmospheric pressure to push the water into the cylinder. The plunger and the cylinder are usually located within the pumpstand.

For deeper wells the pump cylinder must be located below the water level in the well. These pumps need a rod to transfer the mechanical force from the pump stand to the plunger in the cylinder (Figure 9-4). They may be used for wells up to 180 m deep. However, the forces needed to lift the water and the friction caused by the plunger rod increase with depth. Also, the maintenance and repair of such pumps is much more difficult than for suction pumps.

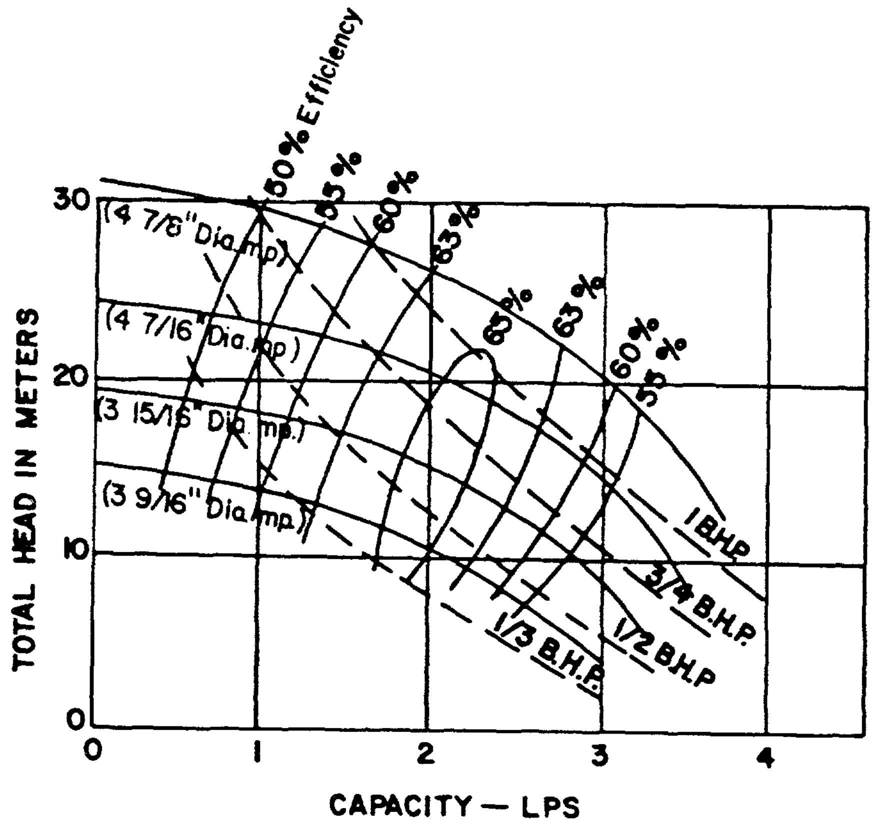
Hand pump installations are important in sparsely populated rural areas. They are described in more detail in other manuals.

Turbine and Centrifugal Pumps

Both types of pumps use a motor-driven impeller to force the water through the pump. The impeller in turbine pumps is shaped to force water in the axial direction (Figure 9-5). In centrifugal pumps, the impeller is shaped to force water outward (Figure 9-6).

The pumps may have only one impeller or may be multistage, where one impeller of the pump feeds into the next. Most deep well pumps are multistage turbine pumps. The characteristics of these pumps can be changed relatively easily by using different types and sizes of impellers, different impeller speeds, and a different number of pump stages. Manufacturers can adapt the performance and characteristics of these pumps to varying situations with relatively few basic components, and designers have a wide variety of pumps from which to select the most appropriate. Their efficiency is high, often up to 85%.

Figure 9-1 Pump Performance Curves for Various Impeller Sizes



Source: Adapted from Republic of the Philippines (1980)

Figure 9-2 Pumped Supply

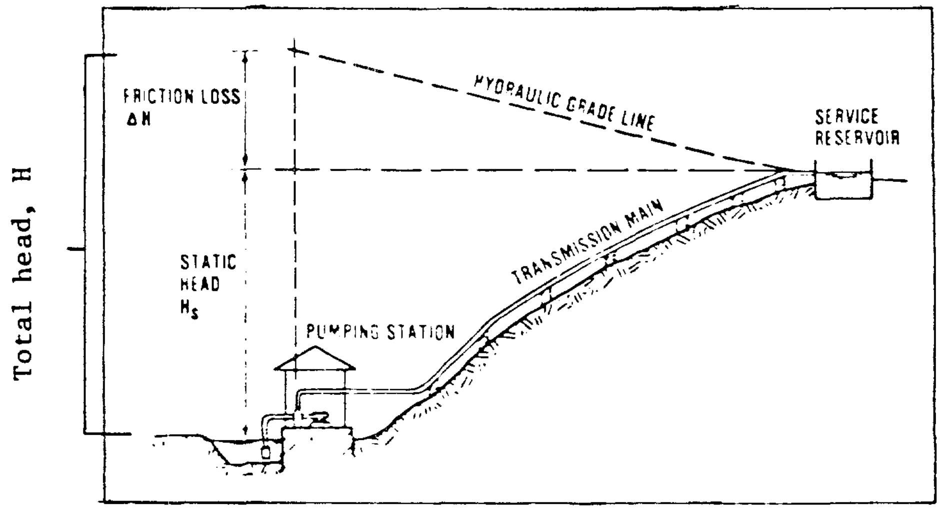
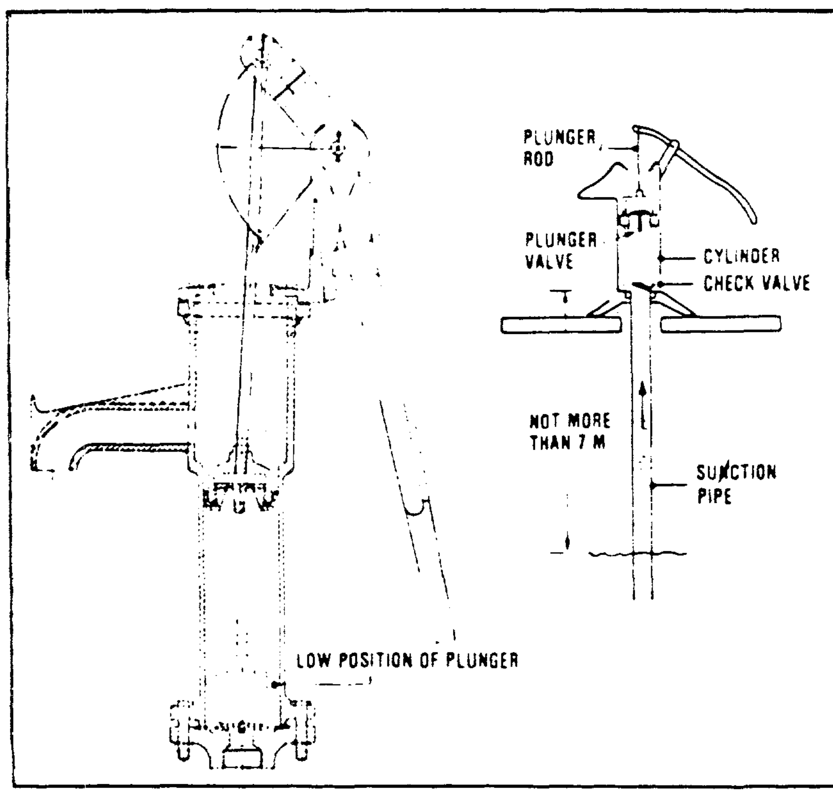
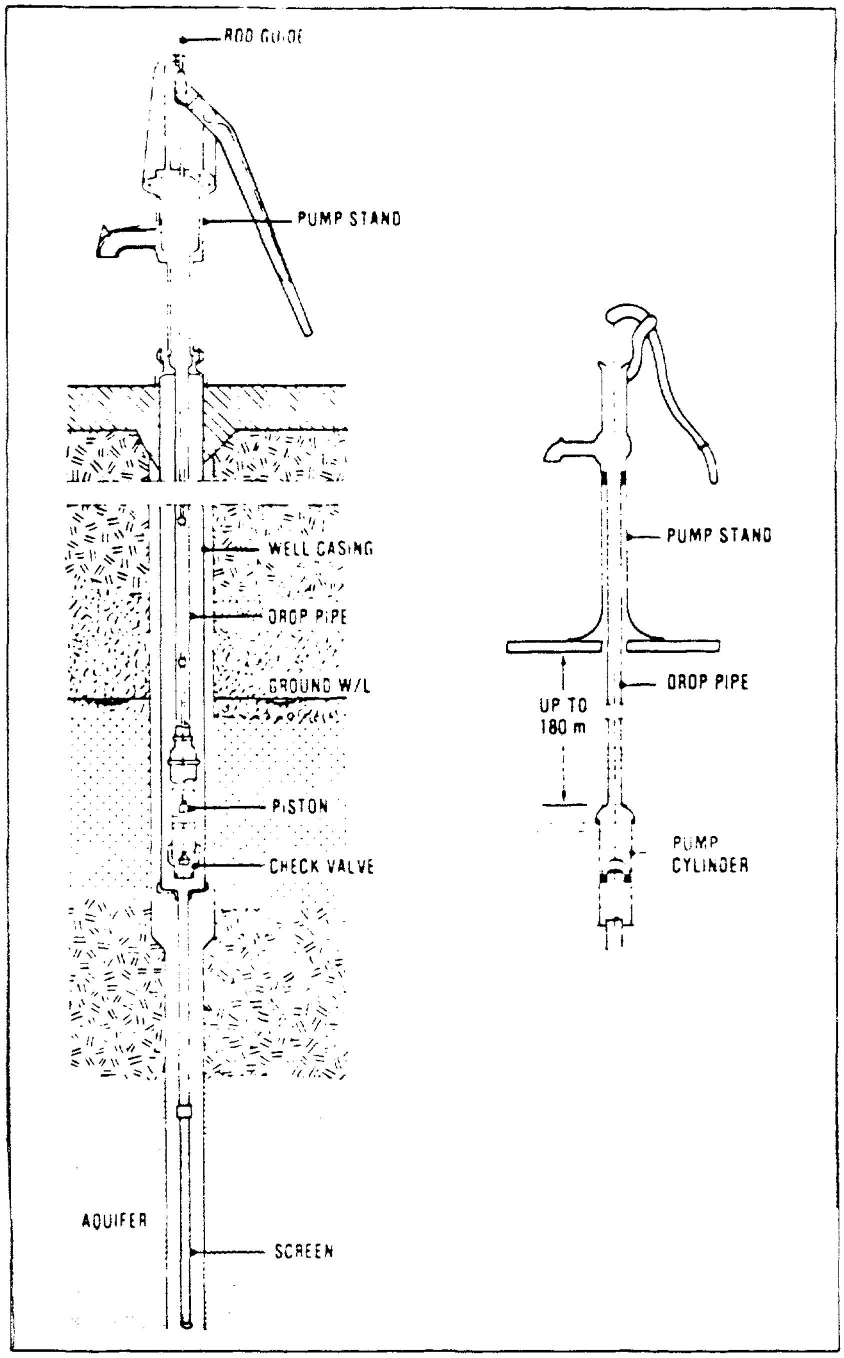


Figure 9-3 Suction Pump (Shallow Well)



Source: Hofkes (1981)

Figure 9-4 Lift Pump (Deep Well)



Source: Hofkes (1981)

Figure 9-5 Axial Flow Pump

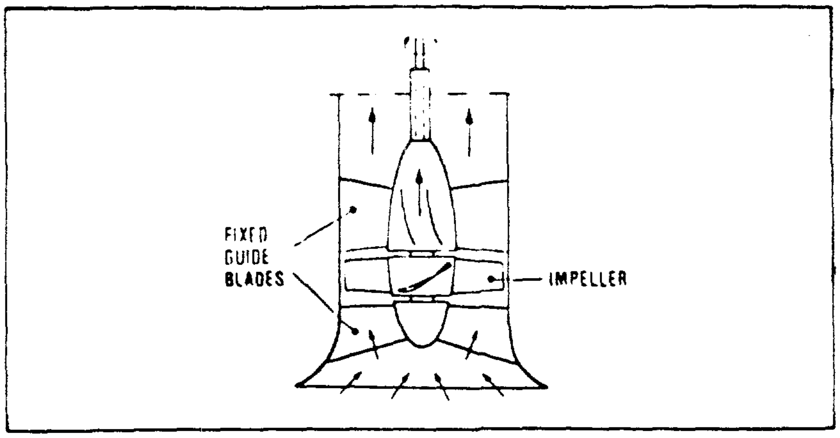
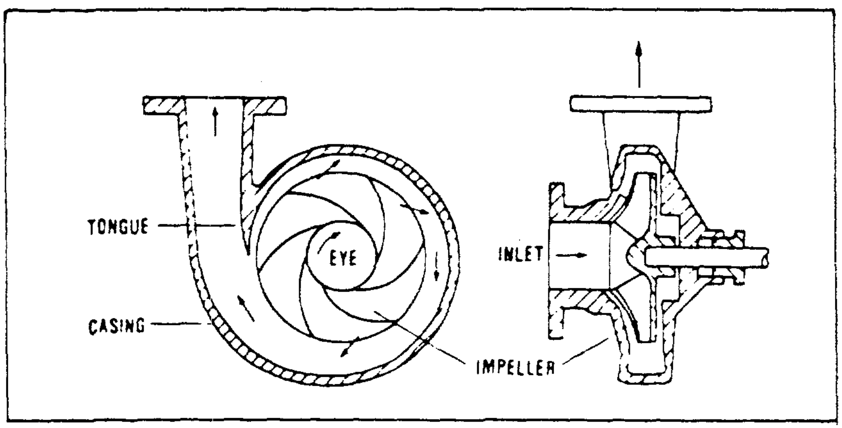
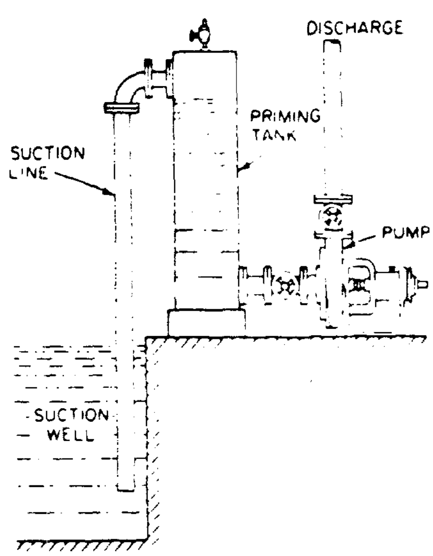


Figure 9-6 Centrifugal Pump (Volute-type Casing)



Source: Hofkes (1981)

Figure 9-7 Simple Priming Tank



Centrifugal and turbine pumps can only operate if they are filled with water. A pump located above the water source must be filled with water, primed, before it is started. The pump can either be filled from a priming tank (Figure 9-7) or by a vacuum-producing device which pulls water into the pump. The discharge pipe should be provided with a check-valve or, preferably, the suction with a foot-valve to prevent the pump from emptying each time it is stopped.

Centrifugal and turbine pumps do not operate well with a high suction lift. The suction lift can be as high as 7 m, but 4 m is preferred. They are subject to an erosion process of the impeller called cavitation, which is reduced by lowering their suction lift and total head.

Centrifugal and turbine pumps are driven by either electric motors, or diesel, gas, or petrol engines.

Displacement Pumps

Displacement pumps are either plunger pumps, like most hand pumps; or rotor pumps, where a rotor forces the water continuously through a specially formed casing called a stator (Figure 9-8). The discharge of the rotor pump is uniform and directly proportional to the rotating speed. Rotor pumps have no valve and are normally easier to maintain. They may be driven by any of a variety of power sources including human, animal, wind or motor.

Shaft-driven and Submersible Pumps

For deeper wells and intakes, pumps are normally placed below the lowest water level anticipated. Two types of drive arrangements exist for such pumps:

1) Drive-shaft pumps are driven by a power source at the surface. The driving force is transmitted through a drive shaft, spindle, or rod (Figure 9-4 and 9-9). The power source, either an electric motor or a diesel or petrol engine, is at the surface and readily accessible for maintenance and repair. However, the installation of drive shafts requires a high precision of the vertical alignment (plumbness) of the well to avoid wearing of the drive mechanism. Long drive shafts need support at regular intervals and flexible couplings to avoid stresses. Shaft drives of more than 30 meters are normally not feasible.

2) Submersible pumps are driven by a submerged electric motor directly attached to the pump (Figure 9-10). A waterproof electric cable connects the motor with the control box at the surface. Submersible pumps are especially useful in deep wells resulting in savings on installation and maintenance costs.

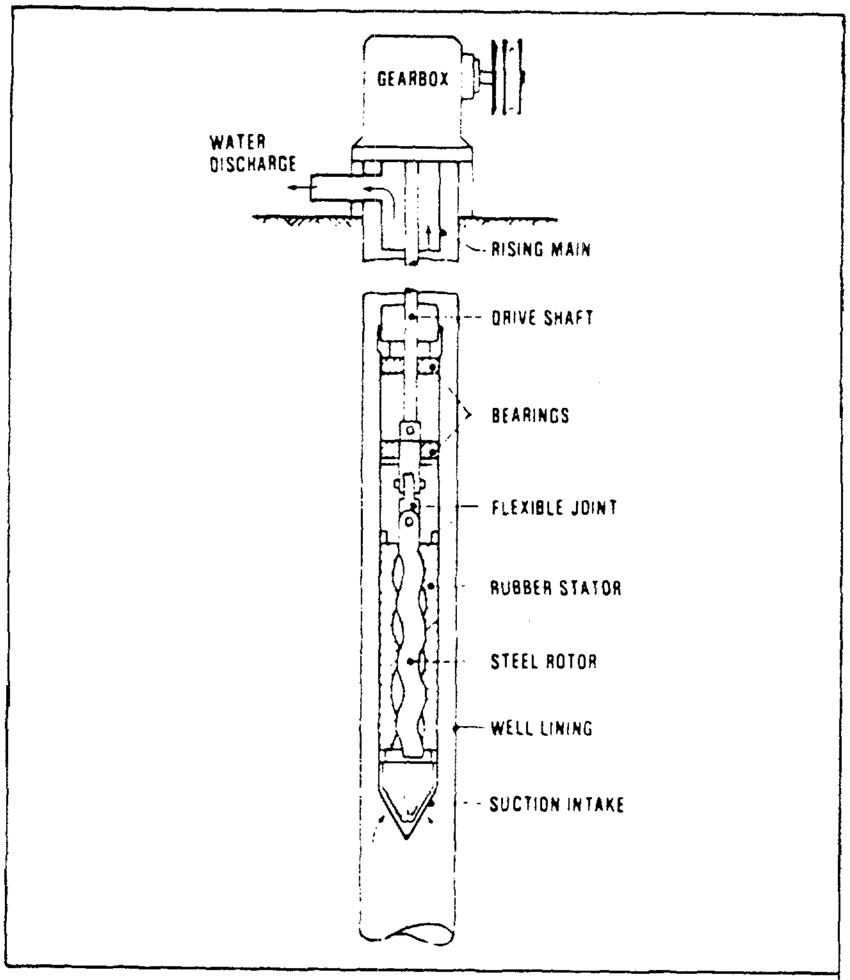
Air lift Pumps

Air lift pumps raise water by the buoyancy of compressed air, which is injected into a discharge pipe fixed in the well (Figure 9-11). The efficiency of air lift pumps is relatively low (25-40%); however, they may be considered in wells or intakes with water of high sand, silt or iron oxide content, which would wear other pumps. Air lift pumps can also be used in wells down to 50 mm in diameter.

Hydraulic Ram

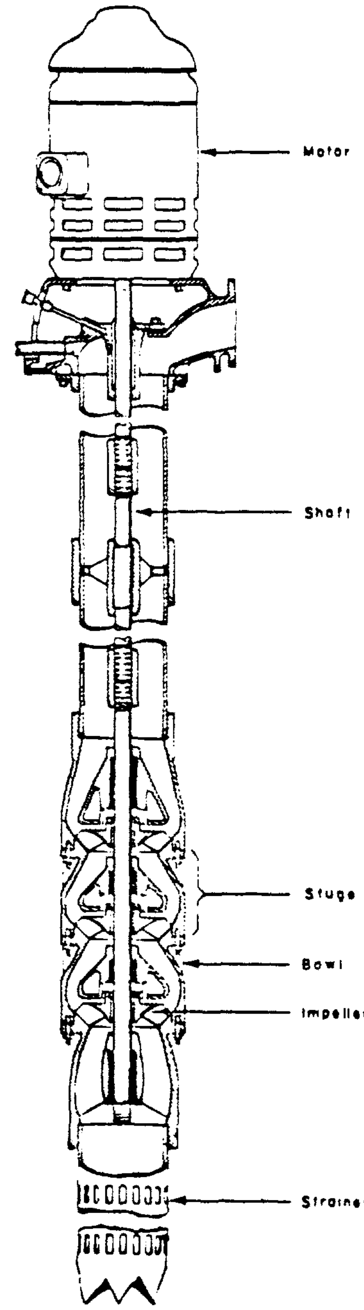
The hydraulic ram uses the energy of flowing water as a drive force to lift part of this water to a higher elevation (Figure 9-12). Hydraulic rams are feasible where much more water is available than required, but the source

Figure 9-8 Helical Rotor Pump



Source: Hofkes (1981)

Figure 9-9 Three Stage Lineshaft Deep Well Turbine Pump



Source: USAID (1969)

Figure 9-10 Pump Driven by a Close-Coupled Submersible Electric Motor

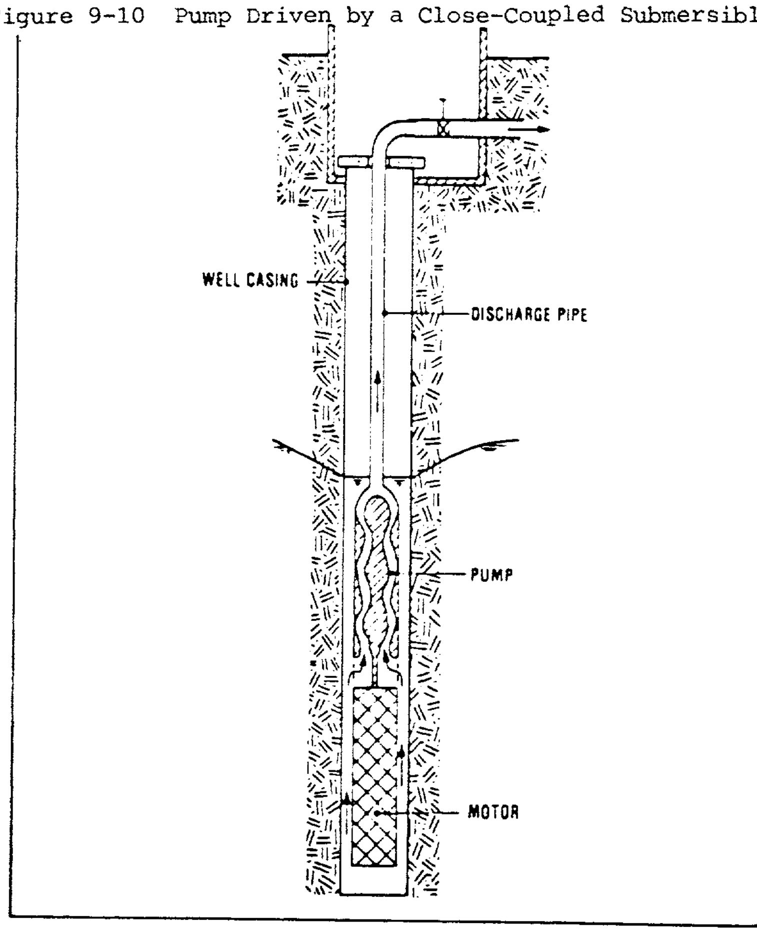
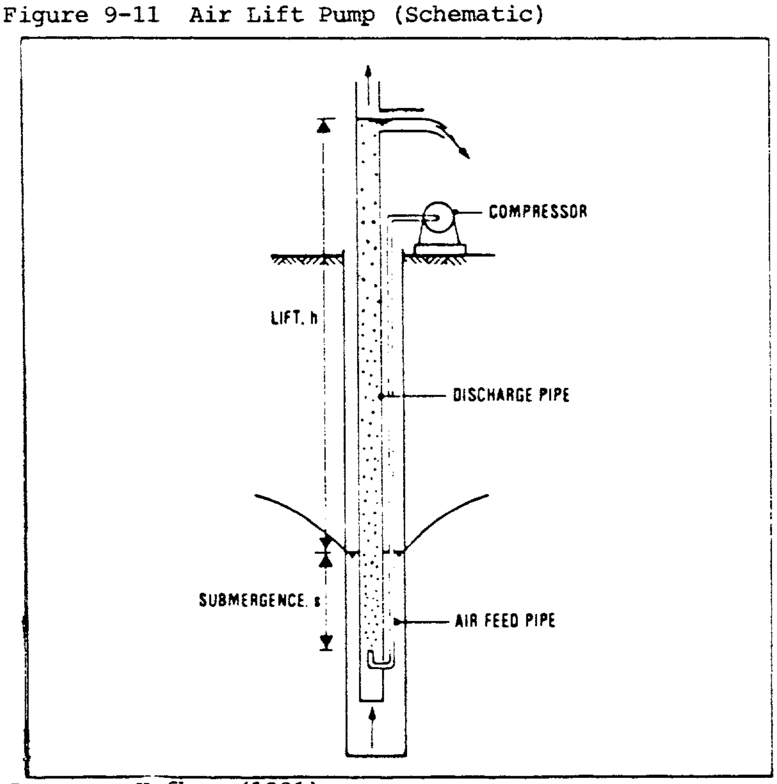
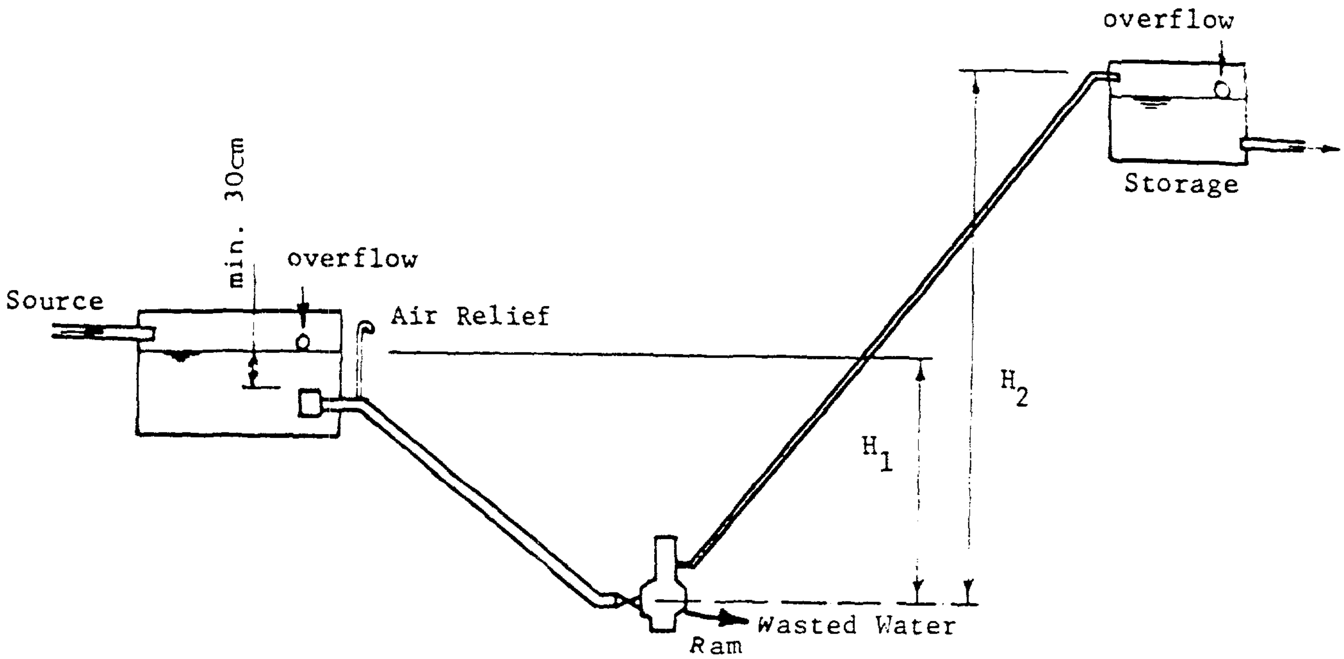


Figure 9-11 Air Lift Pump (Schematic)



Source: Hofkes (1981)

Figure 9-12 Hydraulic Ram



Source: SKAT (1980)

is at a low elevation. The efficiency is best if the delivery head is about 2 to 3 times the supply head. No power source is required and there are no operation costs. Hydraulic rams are simple to make and need little maintenance.

> **Note:** The local manual should provide specifications and characteristic curves of locally available pumps with appropriate capacities.

9.2 Power Sources

Pumps for rural water supply systems are normally powered by hand, electric motors, or diesel or petrol engines. In special cases pumps may also be powered by animals, water (turbine, hydraulic ram), windmills or solar cells.

Human Power

Human power is restricted to small systems; human pumping rates commonly do not exceed about 30 l/min (2 m^3/h) at lift heads of several meters only and may become much lower for larger heads. Experience shows that hand pumps used by the general public, as contrasted with hand pumps for individual households, show excessive wear and maintenance problems.

Electric Power Sources

Where electricity is available from a central supply system nearby, it is the most convenient and economical power source for a pump. Small electric motors are low in initial cost and maintenance and easy to operate. The electric power source should be reliable and not subject to significant voltage variation. If the reliability is low and power outages of several hours are frequent, sufficient elevated storage or an emergency power source should be provided. The required power supply in kw can be estimated from pump tables supplied by pump manufacturers.

Several possible pump start control arrangements are possible. The selection of the starting control depends on the size and type of the pump and the type and stability of the power supply. The design of the starting control should be discussed with a representative of the electrical utility and the pump suppliers. The pump manufacturer should be able to give the minimal safe cycle time (stop to start) for motors and start control devices.

Combustion Engines

In the absence of electricity or as standby in event of power failure, diesel, petrol or gas engines may be used to drive pumps directly. Normally this arrangement is cheaper and more efficient than using a motor-driven generator to produce electricity to drive the pump. However, where submersible pumps are used, an electricity generator driven by a combustion engine is necessary.

> **Note:** The local manual should include a list of available electricity generators of appropriate capacities.

Other Power Sources

In special situations other power sources may become technically and economically feasible.

Windmills are feasible in areas with winds of at least 2.5 to 3 m/sec at least 60% or more of the time. Storage for one to several days should be provided for periods without wind. Most modern windmills require little maintenance. They automatically turn into the wind and turn out of excessive winds.

Water, if available in excess, may either be used to drive a small turbine which drives a pump or be used to lift water with a hydraulic ram.

Solar cells as a power source for pumps are in a developmental stage and have not yet been widely adopted. However, the efficiency of solar cells is likely to improve in the future, which may make them more attractive.

9.3 Pump Selection

The following factors should be considered in selecting pumps:

(1) Required capacity (Q): The capacity of a well pump should not exceed the expected maximum safe yield of the well; and the capacity of pumps feeding into the supply system without an elevated storage tank should be based on the peak demand. If feeding into a treatment plant the pumps should have at least the same capacity as the treatment plant. Where an elevated storage tank of adequate size is available, pumps need to be no larger than the maximum day demand; otherwise they should be chosen to fill it during the assumed filling period (for more detail see Chapter 11).

(2) Total pumping head (H) (Figure 8-17): It is the sum of the static lift, the difference in elevation between the minimum water level of the source, and the maximum water level at the point of discharge, such as an elevated tank or treatment plant, plus the friction losses in the piping and transmission mains. The friction losses are a function of the discharge and the diameter and roughness of the pipe (Chapter 10). The variation of discharge with total head in a system is displayed in a curve called a system-head curve. Its intersection with the pump characteristic curve gives the capacity of the system (Figure 9-13).

(3) Available power sources.

(4) Pump and operation costs.

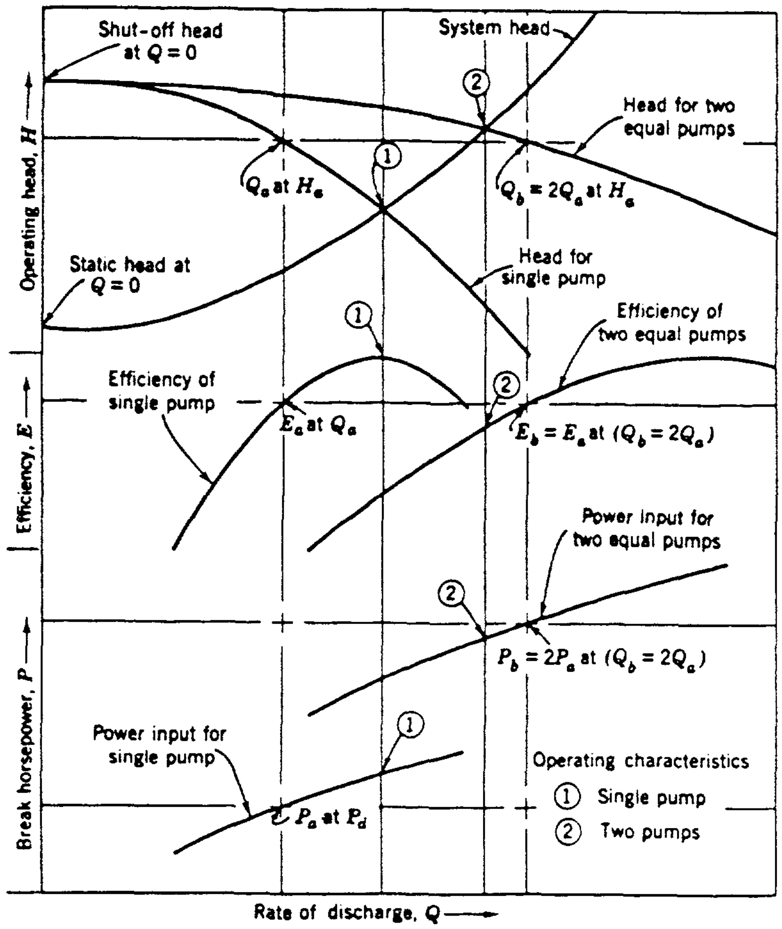
(5) Reliability of maintenance service provided for the available pumps.

(6) Required standard of service. If only one pump and power source is used the supply depends entirely on the reliability of that pump and power source. Preferably, two smaller pumps should be used instead of one large pump; or two pumps can be used, each with the full required capacity, with one serving as standby. Good practice requires that required capacity be provided with one pump out-of-service. Also, an alternative power source should be available.

Where pumps discharge directly into an elevated tank or a treatment plant, without a transmission main, the total pump capacity, not including standby, should be the design capacity of the system, generally based on the maximum day. Where the pump(s) discharge into a transmission main, the pump size depends upon the system-head curve (see Section 10-2). The larger the transmission mains, the lower the system head curve, and the greater the discharge for any given centrifugal pump.

Figure 9-13 shows the discharge-head, efficiency and power curves for a centrifugal pump. The intersection of the discharge-head pump curve with the system head curve shows the discharge and head of the system. The efficiency

Figure 9-13 System-Head Curve and Pump Curves for a Single Centrifugal Pump and Two Identical Pumps Operating in Parallel



Source: Fair, Geyer, and Okun (1966)

of the pump and the power requirements are also shown. Such a graph allows one to choose the pump which has the highest efficiency at the required total head and discharge. The intersection of the system head curve with the pump discharge-head curve should be as close as possible to the maximum point on the efficiency curve.

If two or more pumps are to be used in parallel operation, the pump characteristic curves are added horizontally. The combination of these curves is also shown in Figure 9-13. The interaction of the combined pump curve with the system curve yields the system capacity and the efficiency.

Pump suppliers should provide characteristic curves for their pumps at varying speeds and with various impellers to permit selection of the best pumps for the system. The pump curves may be corrected for losses in fittings associated with the pump, including valves, elbows, etc. Table 9-1 shows typical head losses for pump fittings.

Table 9-1: Head Losses in Fittings

Head losses are estiimated by the following equation:

$$H = k(v^2/2g)$$

where
- H = head loss (m)
- v = velocity (m/s)
- g = gravity constant (9.81 m/s^2)
- k = friction coefficient, see below
- $v^2/2g$ = velocity head
  - = 0.05 m for v = 1.0 m/s; and
  - = 0.20 m for 2.0 m/s

	Value of k		Value of k
Sudden contraction*	0.3-0.5	Valve (open), gate	0.2
Entrance, sharp	0.5	with reducer and increaser	0.5
well-rounded	0.1	globe	10
Elbow, 90°	0.5-1.0	swing check	2.5
45°	0.4-0.75		
22.5°	0.25-0.5		
Tee, 90° take-off	1.5		
straight run	0.3		

*Varying with area ratios.

9.4 Pumping Stations

Pumping stations shelter the pumps and motors and their control devices. Housing may not be required for well pumps where the motors are weather-proof or submerged. Housing is necessary where diesel or petrol engines are the power source.

Pumping stations protect the pump and motor and its control devices from weather and vandalism. The housing should be large enough to allow easy access for maintenance work. Pump houses for deep wells should be provided with a roof opening to facilitate the removal of the pump drive and the piping in the well.

In areas with temperatures below freezing, the station should be insulated. Pump stations in cold areas with electric control equipment may even have to be heated to avoid problems caused by condensation. If the pump is driven with a combustion engine provided with a standby generator, good ventilation must be ensured, and space for fuel storage should be provided.

Pump Control Devices

Control devices normally installed are:

(1) a check valve on each pump discharge to avoid backflow through the pump when not in operation;

(2) gate valves, one on each pump suction and one on the discharge side of each check valve, to permit the pump and check valve to be removed for maintenance;

(3) air release valves at high points in the piping to release air trapped in the pipeline;

(4) a gauge to check pump pressure;

(5) motor control equipment, generally with automatic starting and stopping, based on level in well or elevated tank (this is one instance where automation is justified in developing countries);

(6) a meter to indicate pump discharge (see next section), with totalizer;

(7) a meter to indicate power consumption of motor, with totalizer.

Pumping stations for small supply systems without an elevated storage reservoir may house a pressure tank. Where there is no other treatment, the chlorine feeder, including the necessary laboratory control equipment, is housed in the pump station.

Water Metering Devices

The measurement of the pump discharge is important to (1) monitor pump performance; (2) monitor discharge; and (3) measure the quantity of water supplied to or from a treatment plant or a storage tank, or into the supply system.

Several types of metering devices are used.

Turbine and propeller meters have a rotor mounted in the measuring chamber, which is turned by the flow of water and is connected to a flow register (Figure 9-14). Such meters are accurate for large flows, but inaccurate for small ones. Their only application would be as master meters or for service to factories or large institutions.

Figure 9-14 Propeller Meter

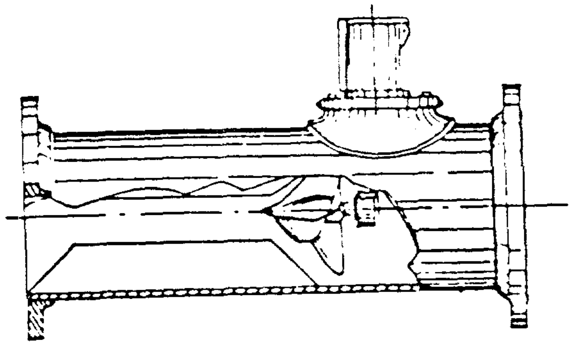
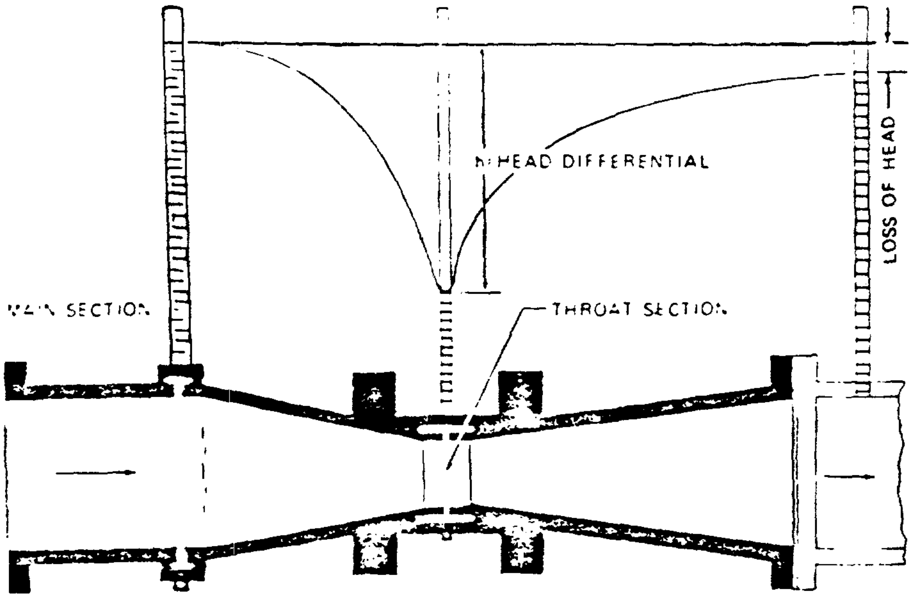
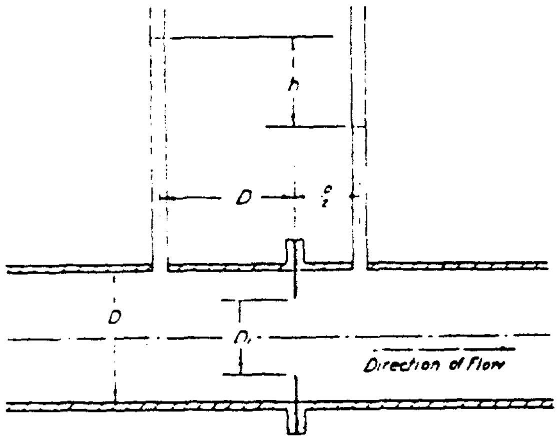


Figure 9-15 Venturi Meter



Source: AWWA, Water Distribution Handbook

Figure 9-16 Orifice Meter



Venturi meters consist of a short throat section. The amount of water passing through the meter is indicated by measuring the pressure difference between the throat and a point upstream from the throat (Figure 9-15). The difference is displayed as flow and may be totalized. Orifice meters are similar to venturi meters but use a thin plate with a circular hole between a set of two flanges (Figure 9-16).

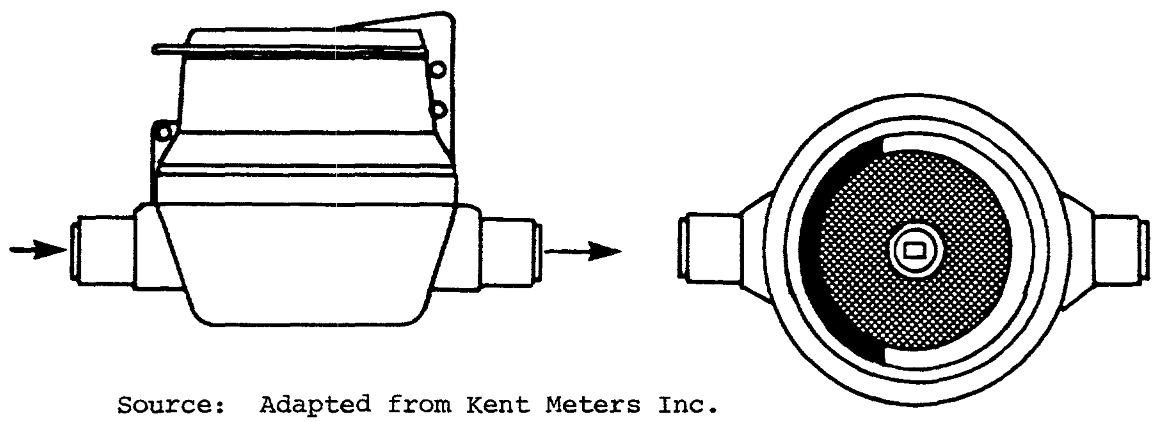
Positive displacement meters contain a measuring chamber in which a disc is moved by the passing water. The motion of the disc drives a flow register dial (Figure 9-17). These meters are normally used for consumer connections up to 50 mm, as they are sensitive to small flows. They may be appropriate for master meters at wells or small supplies.

Proportional meters use orifices to divert a proportional part of the flow through a smaller by-pass pipe with a small meter such as used for house connections (Figure 9-18). The flow through the by-pass is proportional to the flow in the main pipe. This arrangement is suitable for master meters or for large services.

Weirs are suitable at treatment plants or other situations with open channel flow. For occasional measurement of the specific yield of wells or springs, the flow is diverted into a small open channel outside of the pumping station or well chamber. The flow is measured by using a v-notch weir (Figure 9-19). They can be equipped with devices that permit measuring and totalling the flow.

To complement meters in pumping stations, a clock to register the time of operation of the pumps is helpful in checking the meter readings and in determining peak operating rates.

Figure 9-17 Positive-Displacement Meter



Source: Adapted from Kent Meters Inc.

Figure 9-18 Proportional Meter with Positive Displacement Meter

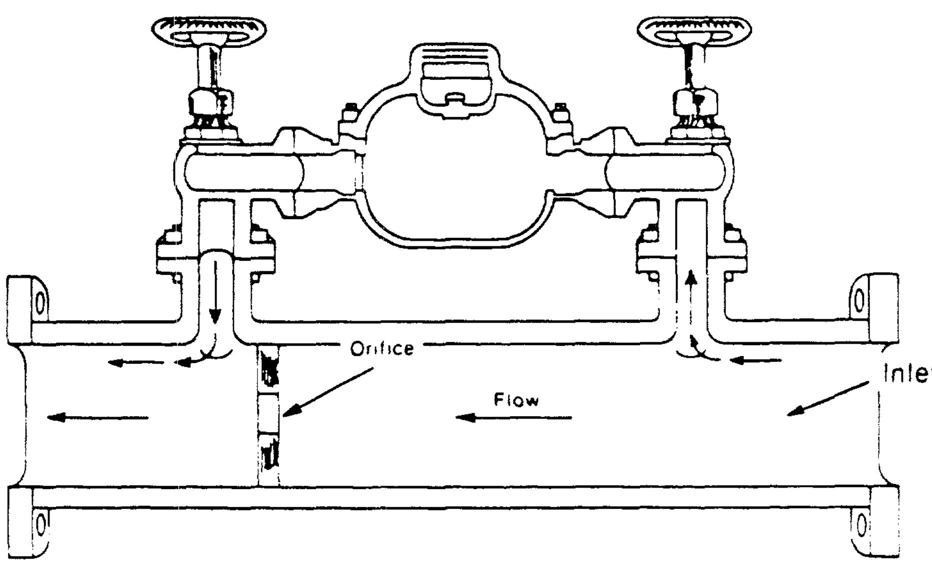
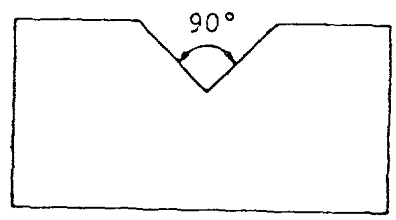
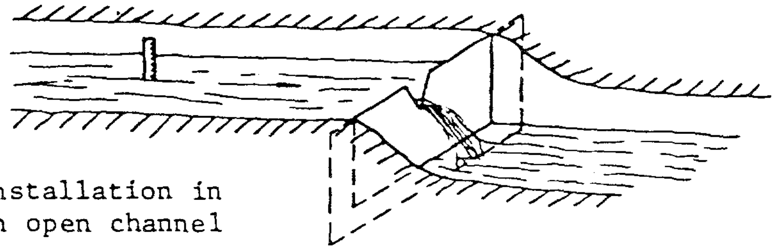


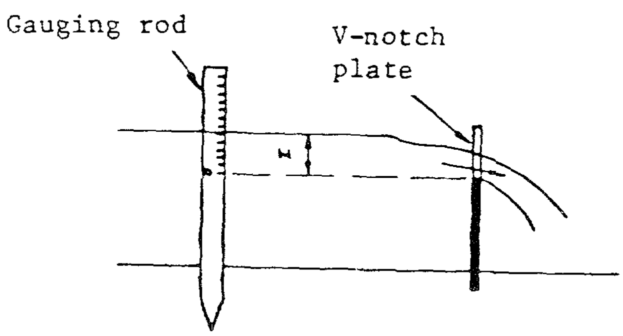
Figure 9-19 V-notch Weir



90°V-notch plate made from metal or wood



Installation in an open channel



Cross Section

Using a 90°V-notch to measure flow

Flow over a 90° V-notch

Height of water H (mm)	*Flow (litres/second)*
50	0·8
60	1·2
70	1·9
80	2·6
90	3·4
100	4·5
110	5·6
120	7·0
130	8·6
140	10·3
150	12·3

Source: Cairncross (1978)

Chapter 10

Transmission Mains

The pipeline between the source and the treatment plant, or between the source and the distribution system, if there is no treatment plant, is the transmission main. Transmission mains, like treatment plants, are designed for the maximum day. If an elevated storage tank is located at the source, then the transmission main may be considered part of the distribution system, and it is designed for the peak.

10.1 Pipe Location

The difference between the elevation of a gravity source and the elevation of the water surface in the tanks into which the transmission main discharges is the available static head. The static head divided by the length of the line gives the available slope of the hydraulic grade line. For pumped systems, the hydraulic grade line is determined from the system-head and pump curves as illustrated in Figure 9-13. The pipe line should not at any point be laid higher than the hydraulic grade line. If the transmission main feeds the distribution system directly, the available static head is the difference in elevation between the source and the elevation of the community, allowing for a desired minimum pressure, which may be 3 to 10 m.

Gravity flow through open channels, either in canals or pipes, is feasible but not generally economical because the pipeline would have to follow the terrain along the hydraulic grade line rather than the shortest route.

The transmission main and its appurtenances should be located so that they can be protected from vandalism, animals, traffic, or natural occurrences such as floods or freezing.

The main should be placed far enough underground that it is protected from structural damage; 0.3 m is the minimum cover required, but up to 1.0 m is recommended, and 1.5 to 2.0 m where the line is subject to heavy truck traffic. In areas where there is freezing, the pipe should be laid below the frost line.

> **Note:** Local data on frost depth, if any, should be provided in manual.

The weight of the earth above the pipe creates external stresses on the pipe, but this is not a problem with the small pipes used in rural systems. However, the pipe material and strength must be chosen to withstand both the expected internal and external pressures. Water hammer can be avoided by pump discharge to an open reservoir or by a pressure relief chamber.

If the pipeline crosses a stream, it may be attached to an existing bridge. The pipeline must be securely fastened, out of danger from traffic, and should be insulated if there is danger of freezing. Also, it should be protected from vandalism. In some instances, a line crossing the stream underground may be preferable.

If a pipeline crosses under a railroad, it should be placed within a culvert or in a specially provided conduit, to avoid transmission of vibrations.

If possible, the pipeline should be laid where it will be accessible, where excavation is simple, and where construction will not interfere with traffic. Laying it along a road or public way is desirable. A permanent record of its location should be made and kept on file. Valves and other appurtenances should be identified and protected.

10.2 Size of Pipes

The transmission main size should be selected to minimize total costs, including the pipe and power costs.

For gravity systems, where power is not required, the minimum size should be selected. This is governed by the available head or the maximum velocity. In general, the maximum velocity should be kept below 3.0 m/sec. If the available head will produce greater velocities, then a break pressure tank may be used. For all other cases, the pipe should be selected by table, chart, or hydraulic formula, based upon the slope of the available hydraulic gradient and the desired capacity, as discussed below.

The flow for which transmission pipes are designed is the rate of maximum daily demand. If the system has no elevated storage tank, and the transmission main feeds directly into the distribution mains, then it must be able to supply the peak hourly demand, which is about 3 times the maximum daily demand. Where the elevated storage tank is far from the points of use, the portion of the transmission line that leads from the tank to the distribution system will have to be designed to carry the peak hourly flow.

The total head loss in a pipe is the head loss per unit length of pipe multiplied by its total length. The head loss per unit length of a pipe at a given flow rate can be found in tables such as Table 10-1, and charts such as in Figures 10-1, 10-2, and 10-3. Knowing (1) the design flow rate; (2) the type of pipe; (3) the length of pipe; and (4) the head available for a gravity system, the pipe diameter can be selected. For example, from Figure 10-1, for a maximum daily demand of 10 m^3/hr, or 167 l/min, with a hydraulic gradient of 10 m/km, a plastic pipe of a nominal diameter of 65 mm would be adequate.

Friction losses in fittings (pipe bends, junctions, and valves), can be ignored in transmission mains and distribution systems because they are relatively small. (The fittings losses associated with pumps and treatment plants do need to be considered. See Table 9-1.)

In pumped systems, the pipe and pump must be designed together. In Figure 9-2, for instance, with a larger capacity pump and more power, a smaller pipe could be used. On the other hand, a smaller pump might be chosen, requiring a larger pipe. For any given situation, there will be one pipe size that is most economical, when both capital (construction) costs and operating (power) costs are considered.

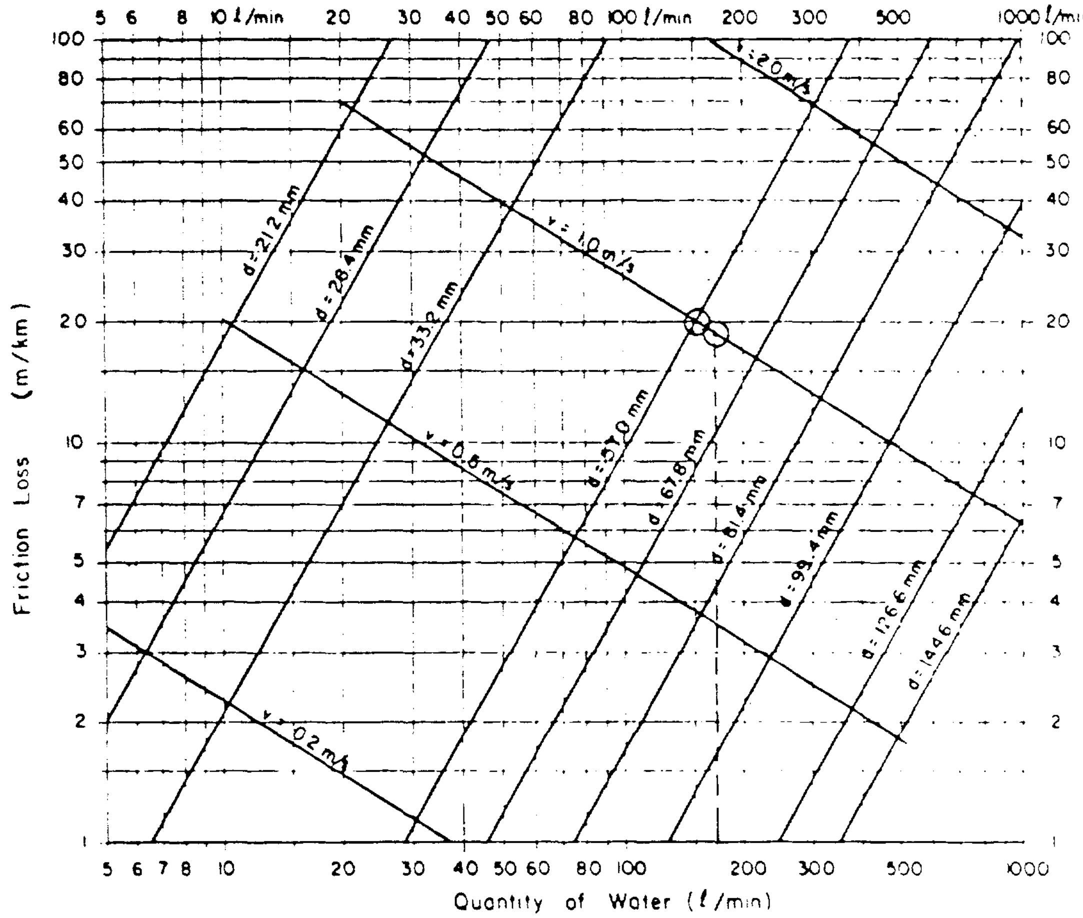
The optimal size depends on the cost of pipe and power, the discount rate, and life assumed for the pipes. The optimum velocity has generally been found to be about 1.0 m/sec. The optimal velocity will be higher if pipe costs are

Table 10-1 Head Loss in Pipes
in m/km for smooth pipes at temperature 20°C

Q in l/s	D in mm 15	20	25	30	50	70	100	120	150	200
0.1	44.1	10.5	3.51	1.45						
0.15	94.1	22.0	7.28	2.97						
0.2	162	37.6	12.3	4.99						
0.3		80.5	26.0	10.5	0.85					
0.5		214	68.1	27.0	2.13					
0.7			129	51.0	3.94	0.76				
1.0				101	7.60	1.44				
1.5					16.2	3.02				
2					28.0	5.15	0.88			
3					60.9	11.0	1.86	0.76		
5					164	29.1	4.81	1.94	0.65	
7						55.7	9.09	3.64	1.20	
10						111	17.9	7.13	2.33	0.56
15							39.2	15.5	5.01	1.19
20							68.6	26.9	8.66	2.04
30							152	59.3	18.9	4.39
50								161	51.0	11.7
70									98.7	22.5
100									199	45.1

Source: Hofkes (1981)

Figure 10-1 Diagram of Friction Loss in Plastic Pipes (PVC and PE)

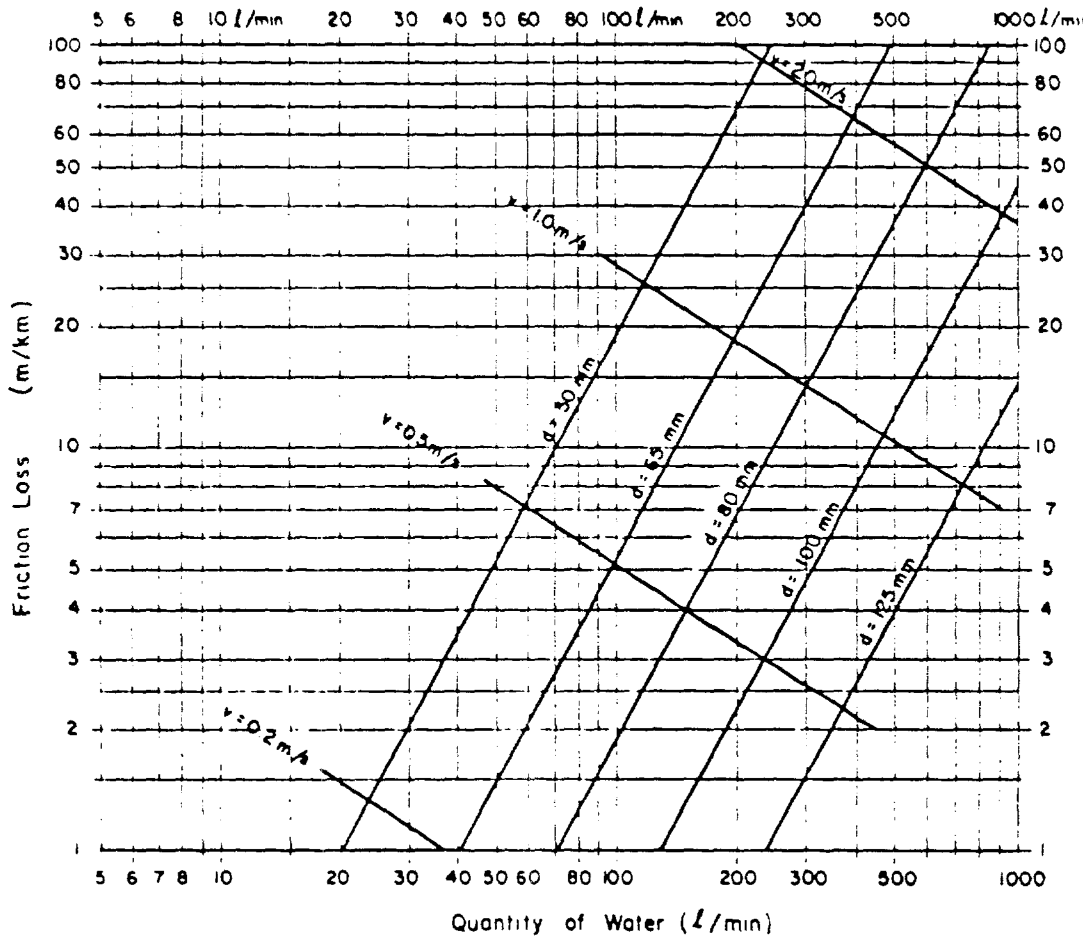


	nominal diameter	outside diameter (D)	t	inside diameter (d)
PE hoses		32 mm	5.4 mm	21.2 mm
		40 mm	6.8 mm	26.4 mm
		50 mm	8.4 mm	33.2 mm
PVC pipes	50 mm	63 mm	3.0 mm	57.0 mm
	65 mm	75 mm	3.6 mm	67.8 mm
	80 mm	90 mm	4.3 mm	81.4 mm
	100 mm	110 mm	5.3 mm	99.4 mm
	125 mm	140 mm	6.7 mm	126.6 mm
	150 mm	160 mm	7.7 mm	144.6 mm

k = 0.01 mm

Source: ENSIC (1983)

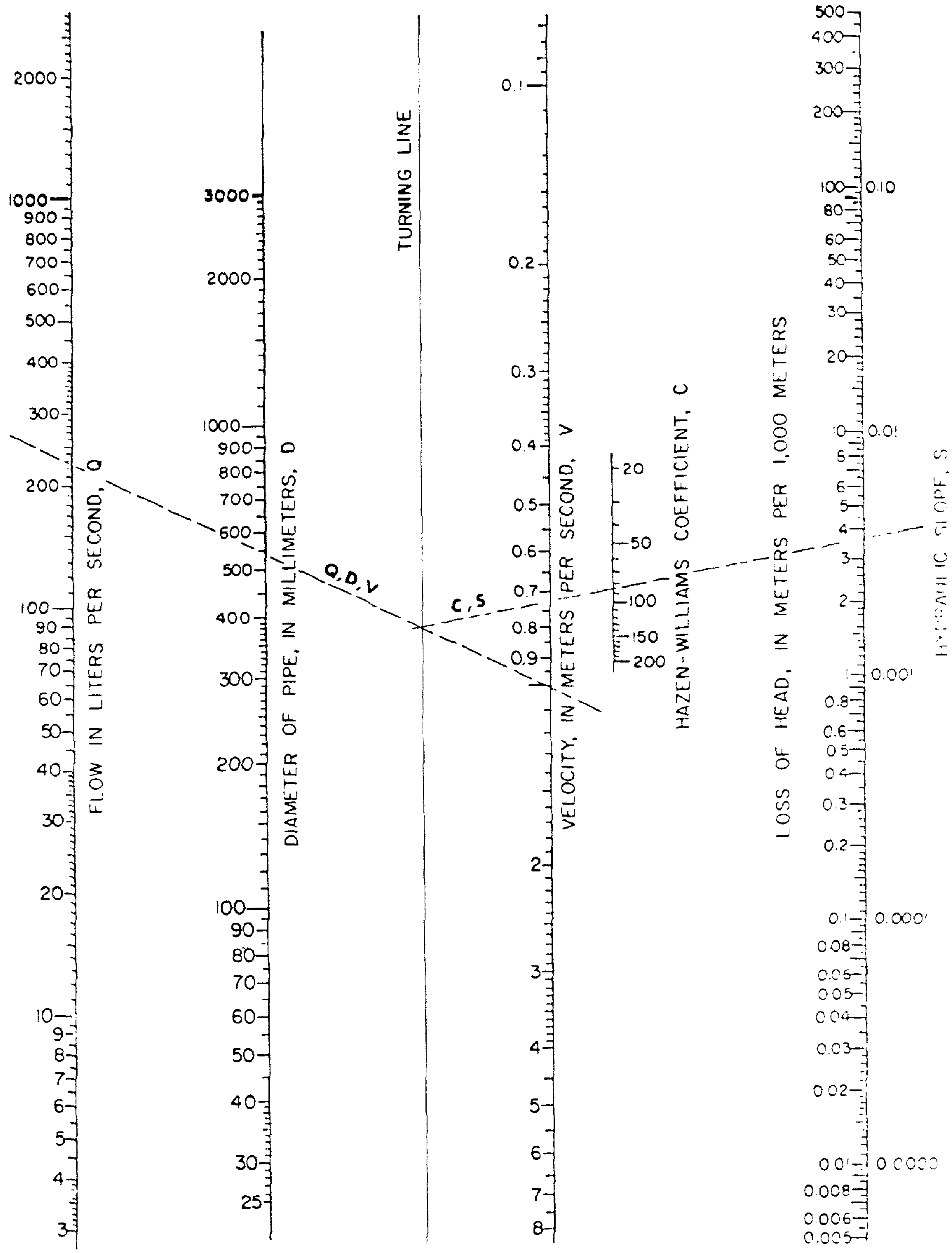
Figure 10-2 Diagram of Friction Loss in Asbestos Cement Pipes
k = 0.05 mm; d = Inside Diameter



Source: ENSIC (1983)

Q D V C S

Figure 10-3 Nomograph for Solution of the Hazen-Williams Formula



Source: McJunkin (1968)

110

high, and power costs are low; while it may be lower if pipe costs are low and power costs are high. Also a higher velocity can be used for design when the pipe is designed for the peak hour, because it occurs a small percentage of the time.

Using local pipe and power costs, and appropriate discount rates and pipe life, it may be useful to calculate the optimum velocity using the methods described in Annex 4. Using a design velocity is much simpler than optimizing each transmission main.

Using an optimal velocity of 1.0 m/sec, for a capacity of 10 m^3/hr (167 l/min), Figure 10-1 shows that a pipe with a nominal diameter of 65 mm would be adequate, which would produce a head loss of 10 m/km. The next smaller size would produce a head loss of about 25 m/km. To this would be added the static lift to get the total head and the pump to be selected should have its maximum efficiency at the total head and a flow of 10 m^3/hr.

The actual delivery of a pump and transmission main needs to be determined from the intersection of the discharge-head curve of the pump, and the system-head curve, as illustrated in Figure 9-13. The system-head curve is constructed by adding the head loss at various flows in the pipe to the static head. This is easily done by using a head loss table, formula, or chart to get the head loss (h_1) for an assumed flow (Q_1) in the system. The head loss at other flows (Q_2, Q_3,...) can be obtained from the charts or calculated by this formula

$$h_2 = h_1 (Q_2/Q_1)^{1.85}$$

The discharge of the system will be at the point where the pump curve intersects the system-head curve.

10.3 Pipe Materials

Steel, galvanized iron, cast-iron, asbestos-cement, and several types of plastic are the most common. Each type of material has its advantages and disadvantages. Plastic pipe of high quality is most appropriate for rural communities where smaller diameters are used. Asbestos-cement may present a health hazard to those who cut and fit the pipe, and possibly to consumers where water is aggressive. Accordingly, AC pipe should be avoided unless feasible alternatives are not available. Factors in selecting pipe materials include:

Strength of Pipe: Select the pipe with pressure ratings adequate to meet the operating conditions of the system. In most low pressure rural water supply systems, any water pipe made to a water supply standard specification is likely to be satisfactory. Pipe not known to conform to an appropriate standard should be avoided.

Type of Soil: Select the type of pipe that is suited to the type of soil in the area under consideration. For instance, acid soil could easily corrode galvanized iron pipe and very rocky soil can damage plastic pipes unless properly bedded in sand.

Availability: Select locally manufactured pipe that conforms to standards if it is available.

Note: The manual should show the various pipe materials, sizes, and strengths locally available.

Ease of transporting and laying the pipe under the topographical and geological conditions of the project (some types of material bend more easily, for instance); and availability of labor skilled in construction of pipelines with that material must also be considered.

Table 10-2 gives some of the characteristics of common pipe materials. Iron is the strongest materials but also the most expensive. Plastic pipes are being used more and more: they are lightweight, easy to work with, do not corrode, are fairly flexible, have low friction factor and are usually the least expensive. However, plastic pipes should not be exposed to sunlight or heat which significantly reduce their strength.

Table 10-2 Characteristics of Different Pipe Materials

Parameters	G.I.	PVC	PE	AC
1) Crushing strength versus superimposed loads in trench	Excellent	Fair	Poor	Good
2) Bursting strength versus internal pressure	Excellent	Good	Good	Excellent
3) Durability	Fair	Excellent	Excellent	Fair
4) Resistance to corrosion	Poor	Excellent	Excellent	Good
5) Flow capacity	Fair	Excellent	Excellent	Good
6) Resistance to external mechanical injury	Excellent	Fair	Poor	Fair
7) Ease of installation	Easy	Must be handled gently and must be buried		
8) Pipe cost	High	Low	Low	Fair
9) Cost per fitting	Low	High	High	Fair

G.I. - Galvanized Iron
PVC - Polyvinyl Chloride
PE - Polyethylene
AC - Asbestos Cement

It is important to establish specifications and a quality assurance system (see Chapter 16) to ensure getting the proper quality of material and correct dimensions for the pipe. Annex 6 provides an overview of information required in the specification of pipe materials.

10.4 Pipe Appurtenances

Fittings and Joints are used to connect pipes; different pipe materials require different types of joints. Unions and couplings are used to connect two pipes of the same size and material. Plastic and steel pipes are joined by welding. Small size galvanized iron pipes have threaded ends to be screwed together. Cast iron pipe have joints in the pipe itself. Clamp-on joints, or unions, are often used for repair work. Reducers are used to connect two pipes of different diameters and to connect a pipe to a smaller valve. Elbows are used to change the direction of flow. Tees are used at branches, to divide the flow between two pipes.

Valves are used to stop or restrict flow. They are used on the suction and discharge sides of pumps, along transmission lines for draining the line, or to isolate sections of lines for repair. Gate or butterfly valves are generally used for such applications. Butterfly valves, being easier to operate, are particularly suitable for treatment plants and pumping stations. Check valves let water flow in one direction but not the other. They are installed on pump discharge lines to prevent water from flowing back through the pump. They are often installed in connections to industries to prevent backflow into the system. Check valves between pure water and possibly contaminated water lines are installed in pairs with a drain between them, for safety in case one leaks.

Air-release valves are used at high points in long transmission mains to keep them from air binding. Air tends to be trapped at high points in the pipeline, restricting the flow, and must be released. Air inlet valves are used to draw air into the pipe to let it be emptied for repair. An open ended vertical pipe that rises above the hydraulic gradient can be used in place of air release and inlet valves. Drains should be provided at low points in the pipeline. These are gate valves that allow water to be drained for repair work or after disinfection.

Thrust blocks are used where pipes change direction and pressure in the pipe exerts a force outward that puts the joints under tension, causing leakage. Thrust blocks are not required for pipes of 150 mm and smaller if they are bedded properly in a trench. Elbows and other fittings in pump stations do need to be anchored.

10.5 Installation and Testing

Laying of the pipe must be done carefully; experienced workers are likely to do the best work. The pipe must be bedded properly along its length on the bottom of its trench, avoiding rocks that can damage the pipe. Proper backfill is essential.

When the pipe has been laid, it should be plugged at the ends and filled with water to a pressure of about 50% above the normal pressure expected during operation. The pipe trench should be partially backfilled to hold the pipe in place, but it is very important to do the pressure test before the trench is completely backfilled, so that leaks can be detected and repaired. The pressure should be maintained for about 15 minutes/100 m of pipe.

The transmission main should be disinfected before being placed in service. This can be done by placing calcium hypochlorite in the pipe as it is being laid in an amount to make a chlorine solution of about 100 mg/1. When the pipe is completed it can be filled with water and allowed to stand overnight.

It is also possible to prepare such a solution outside and pump it into the pipe line.

Chapter 11

Distribution Systems and Storage

11.1 Distribution Systems

Distribution systems are classified as branched networks (Figure 11-1A) and looped networks (Figure 11-1B). Branched networks are relatively easy to design and are less costly to construct in small systems. However, they are less reliable, as any break or maintenance work in the network results in cutting off the supply to part of the system and the dead ends impair water quality. A network can be started with a branched system, with the ends of the branches "looped" at a later time to improve flow conditions and provide greater reliability.

Looped networks are common in densely populated areas. They provide a greater reliability of service than branched systems, eliminate dead ends, and improve flow conditions during periods of high local demand. Looped networks may be designed based on a main loop which feeds into secondary pipes (Figure 11-2) or based on a branched network with several interconnections resulting in loops (Figure 11-3). Looped networks require more valves and fittings (Figure 11-4); the omission of interconnections reduces the number of valves (Figure 11-5) at the price of reliability.

The cost of the distribution network depends mainly on the total length of pipes installed. Therefore the layout of the network should be carefully planned and the future development of the service area should be considered.

Normally, pipes are placed in or along the main streets with branches into residential access roads. To ensure that the pipes can be easily located for future repairs or inspection, a consistent layout system may be adopted, always laying the pipes on the same side of the road.

The depth of the pipe depends on (1) the strength of the pipe material; (2) the traffic load; and (3) the depth to the frost line. The considerations are about the same as for transmission mains, with the exception that distribution mains are constrained to run through many more inconvenient locations.

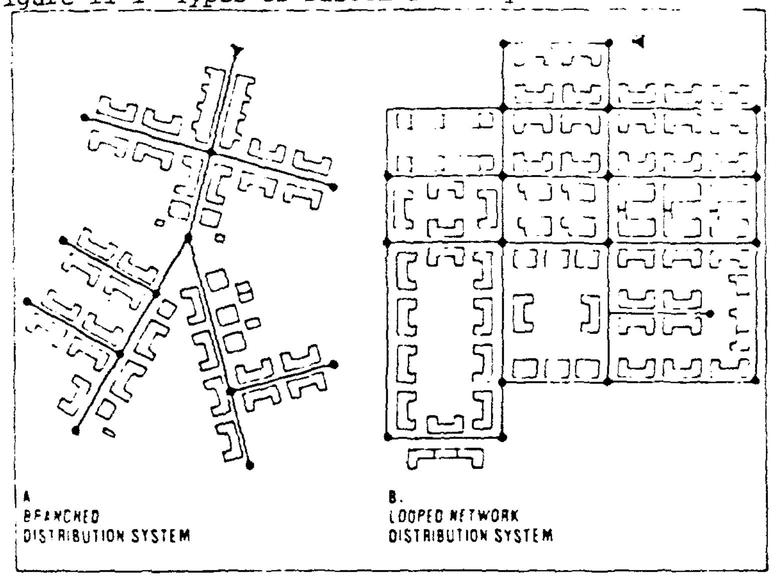
11.2 Service Storage Reservoirs

Water supply systems are well served by elevated service reservoirs (1) to maintain uniform pressure in the distribution system; (2) to store water for use during periods of peak demand; and/or (3) to provide a reserve for supply during pump or power failures. The place of elevated tanks is shown in various system layouts in Figure 4-1.

The advantages of including elevated storage in a system are many:

- It permits the pumps to operate at a low, steady rate, without much on-and-off cycling, thereby lengthening the life of the motors.
- It eliminates the need for pressure tanks for pump regulation.
- It permits much smaller pumps to be used, because they need only to provide the maximum day flow; without elevated storage, the pumps need to provide for peak hourly flow.

Figure 11-1 Types of Distribution Systems



Source: Hofkes (1981)

Figure 11-2 Looped Network with Ring Main

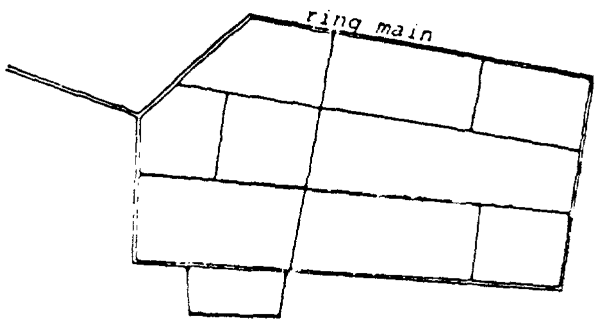
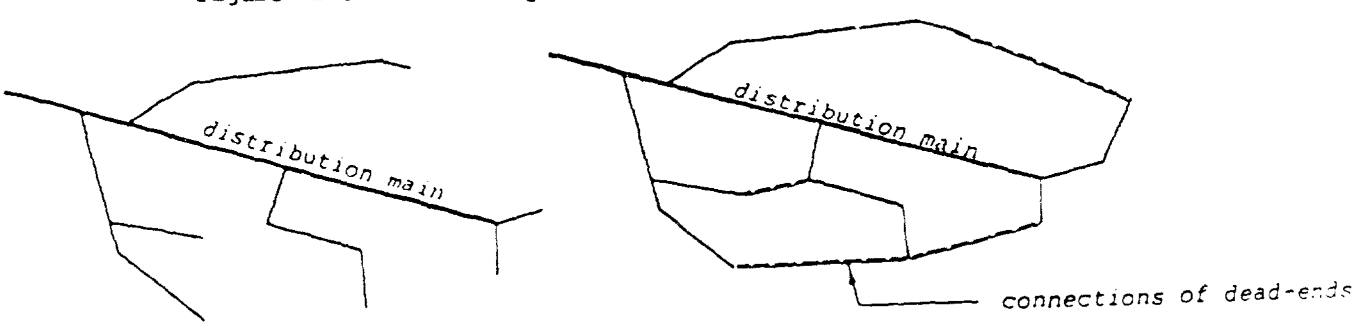


Figure 11-3 Branched System Looped by Connecting Dead Ends



Sources (11-2, 11-3): SKAT (1980)

Figure 11-4 Fully-interconnected Pipes

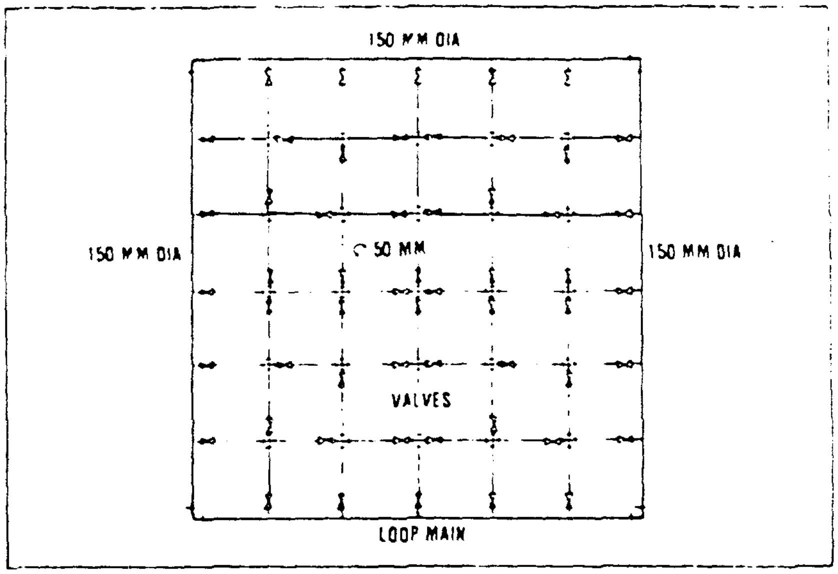
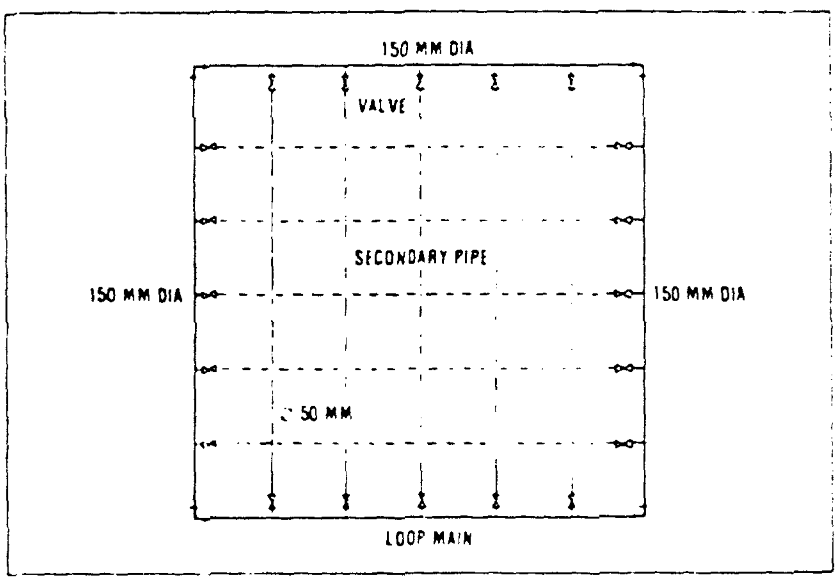


Figure 11-5 Over-crossing Single Pipes



Source: Hofkes (1981)

- It reduces the size of transmission lines because they need to be only maximum-day capacity and not peak hour.
- It reduces the required power capacity for the pumps and the total power used, because the head losses in the system are lower at lower flow rates.
- It reduces the required capacity of the clear well at a treatment plant which is necessary to permit the plant to operate at a uniform rate. It also permits the supply or the treatment facility to operate intermittently while maintaining service.
- It permits simple constant-feed chemical feed devices to be used. This is important where chlorination is the only treatment.
- It may provide contact time for the chlorine where there is no treatment plant.
- It assures water supply during short periods of power failure, which are frequent in many rural communities.
- It provides water for emergencies, such as during transmission line breaks, pump or source failures, and the like.

If the topography permits, elevated storage can be provided in a tank on or in the ground. If a tall building is required in the community, the tank can be placed on or below the roof. If a tower is required, it can be enclosed with curtain walls at the bottom and used for offices, storage of chemicals, equipment, etc.

Pressure tanks, often but inappropriately considered a substitute for elevated tanks, only regulate the operation of distribution system pumps, reducing their frequency of starting and stopping. Their usable storage capacity is only 10 to 20% of the tank capacity. They help maintain pressure in the system but do not provide storage for peak demands, for periods when the supply is shut down, or during emergencies such as power failures. They do not permit intermittent operation of the system. A typical pressure tank installation is shown in Figure 4-1.

The storage capacity of elevated tanks is based on the volume required to make up for hourly variations in demand as compared to the rate of pumping, plus a volume for emergency. If provision is to be made for fire protection, this needs to be added.

Hourly variations in demand are greater in small communities than in larger communities. In rural communities a peak factor of 3, as compared to maximum day demand, is often used. Peak factors in similar systems should be checked to obtain appropriate peak factors.

For 24-hour pumping, storage of 25% to 30% of the maximum day demand would be adequate and for 8 to 10 hours pumping, storage of 50% would be required.

For the 240 m^3/day example, storage for hourly variations would be about 60 m^3 for 24-hour pumping up to about 120 m^3 for 8-10 hours pumping.

In addition, storage should be added for emergency, particularly if there are facilities, such as health clinics, that should have water supply continuously. Generally, about 1/4 of the tank capacity is reserved for emergency. Accordingly, for 24-hour pumping, an elevated tank of 80 m^3 would be required, while 160 m^3 would be required for 8-10 hours pumping. For smaller peak flow ratios, storage would be less.

Pumping for less than 24 hours requires larger pumps, larger storage tanks and greater power for pumping. This is partially offset by reduced operator time. One advantage of beginning with 8-10 hours pumping is that when the demand grows, the time of pumping can be extended and additional facilities are not required.

Location and Elevation

Tank location and elevation affect pipe size and pump requirements. The best choice for service storage, if available, is a ground tank at an elevated location near the community to be served. If the land is flat, the storage tank must be elevated on a tower; it is often convenient to place the tank either at the site of the treatment plant or pumping station (to facilitate operation and maintenance), or at a central location in the distribution network. If the area to be served stretches over a long distance, with the source at one end, the reservoir might be built at the other end of town. This allows the tank to be lower and the distribution pipes to be smaller, because water would be fed to consumers from two directions. Such a location provides added reliability in event of a break in the transmission main.

The required elevation depends upon the local situation such as the length of pipelines to the furthest service from the tank and the height of buildings to be served. For a village with one-floor houses, the elevations would range from 3 to 10 m. Where there are taller buildings, the tank may need to be higher, although individual tall buildings may be more economically served with their own booster pumps and elevated tanks.

If there is a difference in elevation of 60 meters or more between the water level in the tank and lower points in the system, savings are possible by locating part of the storage in a tank at a lower level, providing a zone of lower pressure. Excessive pressure increases the frequency of breaks and increases leakage significantly and increases power costs as well.

Designs of Tanks

Storage tanks are usually built of reinforced concrete; ground tanks may be built of masonry. Tanks should be covered to protect them from contamination. Facilities for venting, overflow and draining are required, as shown in Figure 11-6. The arrangement in B of Figure 11-6 provides for flow through the tank. Another arrangement, where the tank "floats" on the line (A) is more economical in that the same pipe line is used for inflow and outflow. The flow-through tank does provide storage which may be necessary to provide contact time for chlorine.

11.3 Sizing of Pipes

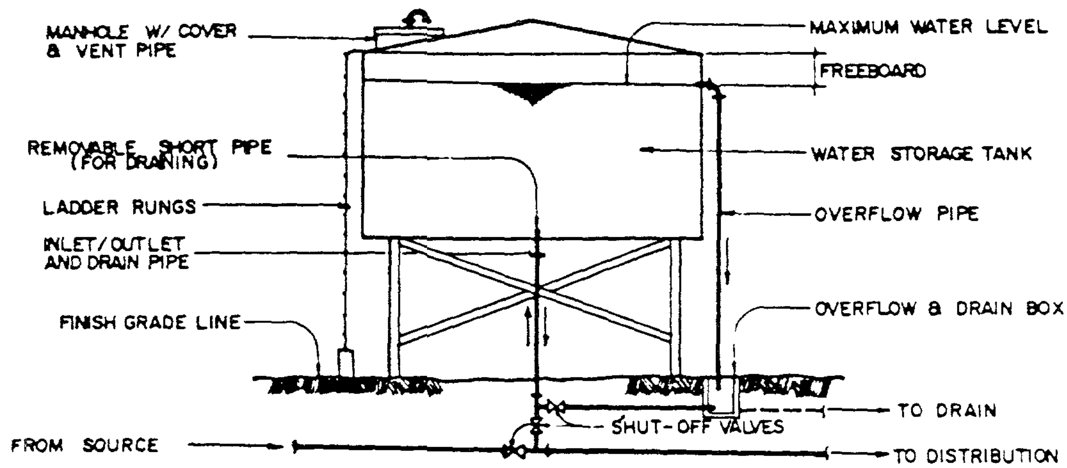
The sizing of pipes in a distribution network is based on:

(1) the peak demand of the consumers.

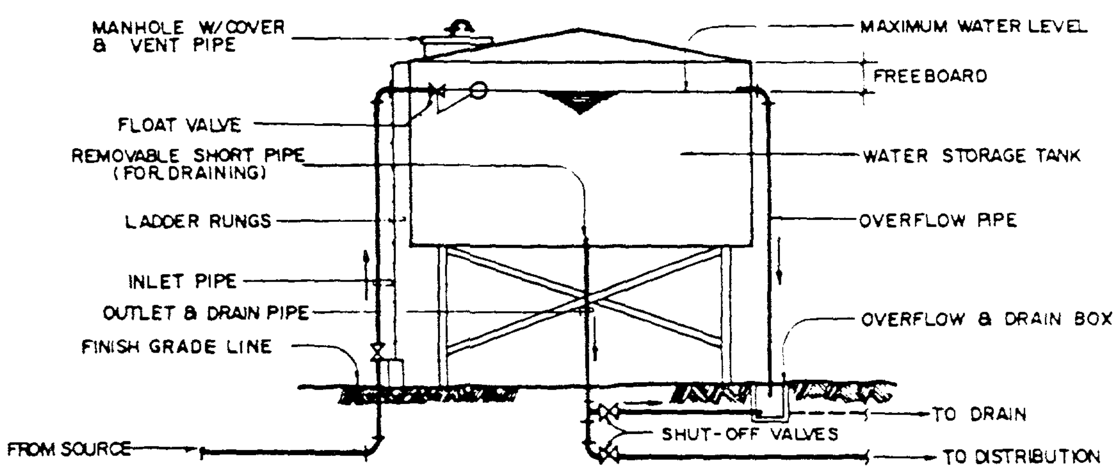
(2) the minimum required pressure head to be maintained anywhere in the network, to protect the network from contamination by backflow of wastewater and infiltration of contaminated groundwater; and to supply services. If future extension of the network is planned, the head losses to these sections should be considered.

(3) the available static head provided by the source feeding into the supply system. This source may either be an elevated tank, a ground reservoir at a higher elevation, or a pressure tank fed by a pump.

Figure 11-6 Elevated Storage Tanks



A. FLOATING-ON-THE LINE



B. FLOW – THROUGH

Source: Philippines (1981)

In principle the pipe sizing is simple: the pressure losses at peak flow should not exceed the difference between the available head and the minimum residual head.

In practice, however, it is more difficult because the available head may itself be varied by pump selection or height selection of service tanks. Larger pumps and higher tanks permit the use of smaller pipes. In small systems without special conditions, pipe sizing can be based on a velocity in the pipes of about 1 m/s at the design flow.

The determination of pipe sizes in branched systems can then be simply done by using the tables in Chapter 10, based on the total demand of the area to be supplied through a given section of pipe and a velocity of about 1.0 m/s. The head loss (in m/km) is read from the table and multiplied by the length of each pipe section. The total head losses for each branch of the network can then be calculated and summed to give the losses in all pipe sections between the source and the end of the pipe. If head loss plus the required minimum residual head are greater than the available head, either the tank elevation (or pump size where no tanks are to be provided) or the pipe diameter must be increased.

The determination of pipe sizes in looped networks without a main loop may be done by assuming a branched network, calculating the pipe sizes, and then connecting the dead ends to form loops.

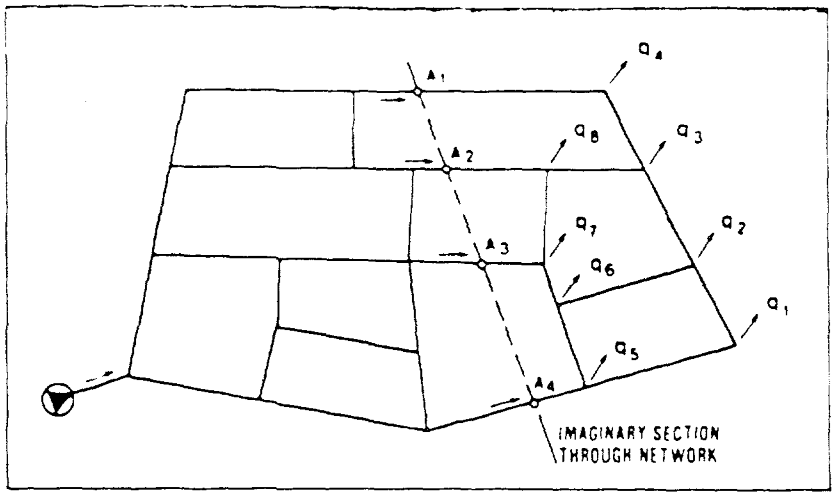
Another method is to draw imaginary cross-sections through the network (Figure 11-7), calculate the total demand through each cross-section based on the number of demand nodes beyond it, and make a first estimate of pipe sizes so that the total cross-section can support that flow at the available hydraulic gradient.

For a larger system or a system with special conditions (for instance, a supply area spread over a long distance or with large consumers in a certain area), the evaluation of several options with the help of computer aided design may be considered. Several programs for microcomputers have been developed to calculate pipe sizes and costs of many possible options in a short time (see Annex 4). In order to simplify the use of computer design, a short manual should be written, describing the data to be collected and the form in which it should be presented.

11.4 Pipe Materials

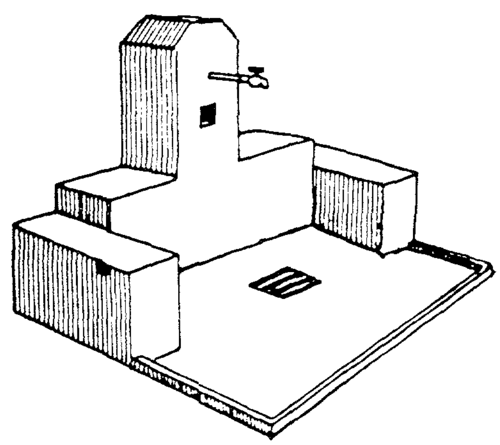
The materials available for distribution pipes are generally the same as those available for transmission mains (section 10-3). More suitable for distribution lines are flexible plastic and galvanized iron, with cast iron being most costly but most suitable where cost and inconvenience of replacement or repair would be high, such as in the main thoroughfare of a community. Selection of service pipe is particularly important because they are more subject to leakage than distribution system pipe. Flexible plastic pipe is preferred over galvanized iron pipe because it is more corrosion-resistant and its flexibility protects against uneven settlement.

Figure 11-7 Imaginary Section Design Method



Source: Hofkes (1981)

Figure 11-8 Public Standpost



Source: Jordan (1984)

11.5 Appurtenances

Valves are most commonly used in distribution systems to isolate lines for repair or to restrict losses during a break.
are gate and globe valves.

Hydrants
Even where no fire flow is included in the design flow, a few fire hydrants to be operated in case of emergency, or to serve as supply stations for public water services such as street washing or construction, may be placed in public places.

Public Standposts
The lowest investment cost for piped service is through public standposts located at points on the distribution system selected so as to be no more than a prescribed distance, from about 50 to 150 m, from any household. The standpost may be designed to serve up to 100-200 households. Each standpost (Figure 11-8) is equipped with one or more taps depending upon the number of households to be served, a concrete pad designed to collect spillage and conduct it to a drain, which is carried away to a soakage pit. The standpost may be fitted with a meter to permit monitoring use and to limit waste.

Standposts at the ends of the distribution system might be designed to serve vendors who distribute water to those outside the service area of the piped system.

A policy decision that needs to be made prior to design is whether the system should be designed to serve individual households, either with yard taps or into the house, in which case the per capita demands and peak demands will be greater than where only standposts are used. The distribution system piping, and the supply works, can be designed for house connections even though these may not be installed for some years.

Service connections carry water from the distribution network to houses to be served. They include a connection to the distribution main and a service line to a valve near the house, or a meter if there is to be one. Although the community does not provide the plumbing inside the house, it should (1) establish a plumbing code; (2) provide advice on installation of plumbing; and (3) make a sanitary inspection before the valves are opened and water is delivered to the house to be certain that the plumbing system is installed properly.

Meters are required for effective water management. They are placed where the service connection connects to the house plumbing system. The meter may be placed outside for more convenient meter reading, in which case it needs to be protected from vandalism, freezing, and animals. Meter boxes are used when meters are placed underground. Service connections and meters create significant head losses. Typical valves are shown in Table 11-2.

It is often advisable to put meters inside the house where they are protected. In multifamily buildings individual meters should be provided for each household, as it has been demonstrated that water waste is reduced when compared with the use of a master meter for the entire building. Where a housing estate is to be served, with common areas such as lawns, a master meter is desirable in addition to individual meters.

Table 11-2 Typical Head Losses (m) in Service Connections with Meters[a]

Flow lpm	0[b]	5	Service 10	Connection 15	Length, m 20	25
5	0.3	0.6	0.9	1.2	1.5	1.8
10	1.6	2.4	3.2	3.9	4.7	5.5
15	3.0	4.8	6.5	8.3	10.1	11.9
20	5.1	7.9	10.7	13.5	16.3	19.1

[a]Based on smooth 1/2-inch (13 mm) pipe and 5.8-inch (16 mm) meter.
b

Source: Adapted from American Water works Association Distribution Manual

Standards should be set up for appurtenances so that their cost and the required material can be included in the estimate of material requirements.

> **Note:** Local standards for service connections, meters, meter boxes and plumbing codes should be incorporated in the manual.

Chapter 12

Treatment

One objective of planning is to select the best quality source that is economically feasible, to minimize dependence on treatment. The selection and design of treatment processes is to keep them as simple as possible and to assure their proper operation with a minimum of attention. The technology necessary for water treatment in rural communities is well established and it is rare that innovative treatment will be advantageous. Guidelines should emphasize (1) dependence on local materials for construction operation; and (2) reliability, with a minimum of mechanical equipment (Schulz and Okun, 1984).

Following is a summary of the treatment processes most likely to be required for rural water supplies. Individual processes are described in detail later in this chapter.

12.1 Treatment of Groundwaters

Groundwater is the preferred source of water for rural communities because it is generally of high quality and requires little treatment.

No Treatment

Gravity springs and deep well supplies may be quite safe without disinfection, if the source can be protected against contamination. This needs to be affirmed by a sanitary survey and bacteriological examination of the water.

Disinfection Only

Groundwater, with disinfection as the only treatment, is the most common type of supply for small communities. Calcium hypochlorite or bleaching powder are most appropriate. Sodium hypochlorite, liquid chlorine, ozonation and ultraviolet light are not likely to be feasible. On-site hypochlorination is feasible if units are manufactured locally and experience in their use has shown them to be reliable.

Iron Removal

Many groundwaters are high in iron and/or manganese. These pose no health problem but their removal is often desirable because they discolor the water, clothes, and rice. The most common treatment is aeration, generally by spraying, followed possibly by sedimentation if the iron content is very high, and slow or rapid filtration. Manganese removal may often be improved by chlorination before filtration. If the source is protected, and the treatment facilities enclosed, disinfection may not be necessary.

Fluoride Removal

Excessive fluorides are a serious health problem. Where fluorides need to be removed, the most suitable approaches are by ion exchange in activated alumina or bone char filters or by coagulation with alum or aluminum trichloride. Defluoridation is costly and not always effective, so selection of an alternative source, even at greater cost, may be the most feasible solution.

Softening

Hard waters make for difficulties in clothes washing. With the availability of modern detergents for washing, softening is not likely to be justified, given its high cost.

12.2 Treatment of Surface Waters

Disinfection Only

All surface waters must have at least disinfection. If the waters meet turbidity and color standards without other treatment, disinfection alone will suffice. Where surface waters are highly colored or turbid, resulting in a high chlorine demand, then treatment as discussed below may be justified prior to disinfection. Where water is polluted with wastewaters, treatment beyond disinfection is certainly required.

Slow Sand Filtration

Where surface waters exceed the 5 NTU turbidity standard but are low in turbidity the year around, generally under 50 NTU, slow sand filtration is appropriate. Such filtration requires no pretreatment, is simple in construction and operation, low in cost and is well-suited to rural communities. Roughing filters may be useful to prepare waters with slightly excess turbidity. Disinfection is required after filtration.

Rapid Sand Filtration

Most river supplies or other surface supplies that are high in turbidity, even if only during the wet season, require rapid sand filtration, with pretreatment generally consisting of chemical coagulation, flocculation and sedimentation. Slow sand filters clog too quickly.

If the turbidity during flood periods is in excess of 1000 NTU, presettling is helpful. Screens may be necessary to keep debris and large fish out of the treatment plant.

Coagulation requires the addition of chemical coagulants, and sometimes coagulant aids and alkalinity. These are mixed into the water, which then undergoes a period of flocculation (slow mixing), followed by sedimentation of the coagulated particles, after which the water is filtered.

If surface waters are of good quality the year around, under about 50 NTU, direct filtration may be used, omitting flocculation and sedimentation.

Activated Carbon Treatment

Should it be necessary to draw water from a source with excessive taste and odor or from a highly polluted source, activated carbon may be useful. Powdered activated carbon is added with the coagulant to adsorb tastes and odors. It is not too expensive because it needs to be used only during those periods when tastes and odors are troublesome. Granular activated carbon filters are used where waters are heavily polluted, particularly with synthetic organics. They may replace or follow rapid sand filters. Granular activated filters are costly to construct and operate; the carbon needs to be recharged or replaced fairly often; they are not appropriate for rural water supply systems, even in industrialized countries.

12.3 Chemicals

Chemicals are used for disinfection, coagulation, pH and corrosion control, fluoridation and defluoridation. The methods of storing, handling and feeding depend upon the chemical, and the importance of reliability.

Many chemicals are themselves corrosive so that storage vessels, feeders and piping used to conduct the chemicals must be suited to the chemical. In small plants, chemicals are generally stored in the containers in which they are purchased. The following are appropriate materials for handling the more common chemicals:

Alum - stainless steel, wood, high-quality ceramic, stoneware.

Calcium hydroxide (slaked lime) in suspension - in iron or steel, rubber, or high-quality plastic; tends to clog pipes.

Chlorine, calcium hypochlorite, and bleaching powder - ceramics, glass, or rubber.

Ferric chloride - rubber, glass, ceramics, high-quality plastics.

Ferric and ferrous sulfate - rubber, iron, stainless steel, wood.

Sodium carbonate - in solution, in iron, steel or rubber.

Sodium fluoride - in solution, in rubber, plastics, stainless steel.

> **Note:** List water treatment chemicals available locally and the way they are purchased. Also, make a table like 12-1 for all common chemicals.

Proper storage space must be available, sufficient in capacity to provide chemicals between shipments. More space is required in more isolated locations. Safety in handling is important, and storage areas need to be protected from exposure and moisture.

12.4 Disinfection with Chlorine

Disinfection with chlorine is by far the most widely used treatment for water supply, and is most appropriate for water supplies in developing countries because it is reliable, generally most economical, and because it can provide a residual which is easily measured. The presence of a chlorine residual after about 30 minutes contact at normal pH assures microbiological safety, without the need for bacteriological analysis. The lower the pH, the more effective is the chlorine. Chlorine does create THMs (see Section 5.1).

Hypochlorite and Bleaching Powder Compounds

Calcium and sodium hypochlorites and bleaching powder, chlorinated lime, are most commonly used. Table 12-1 indicates the characteristics of these chemicals. Calcium hypochlorite is the most stable, losing 3 to 5% chlorine per year if enclosed. Therefore, its dosage is most easily regulated. Bleaching powder is less stable but is generally less costly. Because it loses strength rapidly, the chlorine concentration of the feed solution must be checked frequently. Sodium hypochlorite, which is a solution, is seldom used because it is more voluminous for the same dose of chlorine and it tends to lose strength with time. The choice is based on cost and reliability. If sodium hypochlorite solution is available nearby, it is desirable because it is most easily handled. Where the chemical needs to brought in from a distance and stored, calcium hypochlorite or bleaching powder would be most desirable.

Table 12-1 Chlorine Compounds

Type	Formula	Form	% Available Chlorine	Containers	Feeding
Calcium hypochlorite	$Ca(OCl) \cdot 4H_2O$	Powder	60-70	Cans or drums	1-3% solution
Bleaching powder (chlorinated lime)	$CaO \cdot 2CaOCl_2 \cdot 3H_2O$	Powder	25-35	Drums	1-2% solution
Sodium hypochlorite	$NaOCl$	Solution	10-15	Glass or plastic	1-3% solution
Chlorine	Cl_2	Liquified gas	99	Steel cylinders	Gas or solution

These compounds are fed in solution, which are made fresh frequently, preferably daily. For a chlorine dose of 5 mg/1 for treatment of 240 m^3/day, at a 2% solution, a storage vessel of about 60 liters would be adequate. For larger plants, two storage vessels might be used, with a solution being made up in one while the other is feeding, with the vessels filled on each shift.

Hypochlorite Generators

For communities in remote areas where chlorine compounds are not available, on-site hypochlorite generators that produce chlorine gas by electrolysis of a brine solution might be used if they are manufactured in the country. However, they have the following disadvantages: (1) they are more difficult to maintain; (2) they require electricity; with a gravity supply, a power failure would result in water being produced without disinfection; and (3) they require a brine solution, or salt for preparing brine.

12.5 Solution Feeders

Some of the designs suitable for feeding hypochlorite or chlorine bleach solutions are also appropriate for feeding other chemicals used in water treatment.

General guidelines for chemical feeders are:

1) a minimum of two tanks should be provided at each application point, so that feeding is not interrupted when one tank is out of service for cleaning or filling; where chlorine solutions are being fed, two feed units should be available;

2) the combined capacity of the chemical feeders should be equal to the maximum dosage anticipated;

3) concrete, ceramic or stoneware vessels are useful; they should be adequately protected against corrosion;

4) drains should be provided in each vessel to facilitate flushing accumulated sediments;

5) provision should be made for either hand-operated or motor driven paddles for making up the chemical solutions;

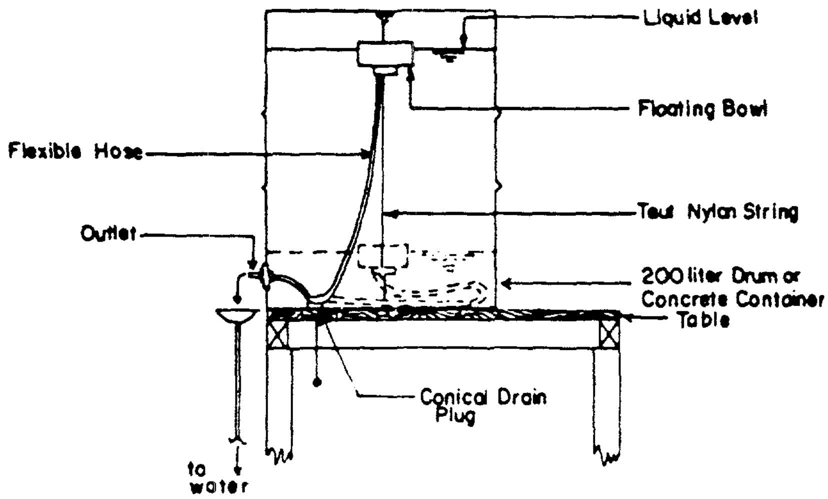
6) chemical feed lines made from rubber or plastic hose should be supported at short intervals, or placed inside a tile pipe for protection, with provision for easy cleaning;

7) chemical feeders should be as close as possible to the point of application of the chemicals.

Constant-rate solution feeders are widely used (Figure 12-1). For most units two solution tanks are connected to one feeder so that one tank can be filled and mixed while the other is operating.

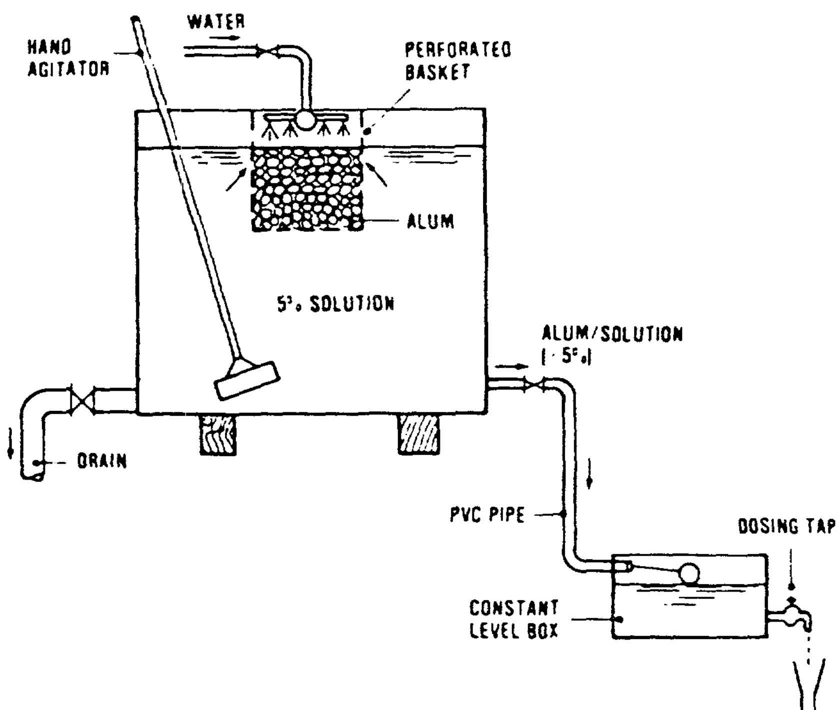
When a water supply is pumped at irregular intervals, with frequent on-and-off cycles, as is the case with well systems without elevated storage tanks, some provision must be made to turn the feeder on and off synchronous with the pump. This cannot be done manually because of the frequency of cycles, on the order of minutes in small systems. It can be done by connecting a solenoid valve on the chemical feed line to the pump motor, so that when the pump starts up, the feed line is opened. Another approach is to use a simple positive displacement pump, interconnected with the water pump, for pumping the chemical solution.

Figure 12-1 Solution Feeders



a. Floating-bowl hypochlorinator

Source: Adapted from AID UNC/IPSED (1966)



b. Constant-head alum feeder.

Source: IRC (1966)

Note: Identify local pumps that may be suitable for chemical feeding.

12.6 Coagulation

Coagulants should be available locally, low cost, effective in forming good floc particles, and free of health hazards.

The most commonly used coagulants are alum and potash alum. Ferric salts, such as ferric sulfate or ferric chloride, are often used. The ferric salts are attractive because they are often available at low cost as the waste product from steel manufacture. Also, ferric salts operate well at a wider pH range (5.5 to 9.0) than alum salts (6.5-7.5) and the iron residuals are easier to control and are of less health consequence than aluminum residuals. However, iron salts are not so easily fed as alum salts and are generally less suitable for small communities because of their corrosivity.

Coagulant aids, polyelectrolytes, are often used in larger facilities to reduce coagulant dosages and to improve performance. Synthetic polyelectrolytes are costly, but natural polyelectrolytes may be available locally (Schultz, Okun, 1984).

Jar Tests

The best approach to selecting coagulants, and to determining whether alkalies are necessary, or whether coagulant aids would be helpful, and their optimum dosages is through the use of jar tests. Jar-testing units, which are commonly available in larger plants, should be available in central laboratories.

Experience with a similar water at a nearby plant is a guide to the best coagulants to try. Coagulation is better at higher temperatures so that the results at warm temperatures may not be indicative of requirements in winter. Planners at the national level should examine the availability of other coagulants or coagulant aids made from indigenous plants, from waste materials from agriculture or industry, or from ores available locally.

Rapid Mixing

Dispersal of the chemical throughout the water to be treated is accomplished by introducing the chemical at or before a point where the water undergoes great turbulence. The turbulence can be induced either mechanically or hydraulically. In rural systems, hydraulic mixing devices are preferred over mechanical mixing, because they are lower cost, require less maintenance, and can be built locally.

Mixing can be accomplished by introducing the chemical before the raw water pumps, if this is convenient. However, this is not advisable where the chemicals are highly corrosive as they may damage the pump impeller.

Where the water enters the plant in an open channel, a hydraulic jump can be created, often in conjunction with a flow measuring flume. The chemicals can be added in the turbulent portion of the jump.

A more common approach is to use a free-falling weir which may be required in the design or can be specially provided for mixing. The chemical solution is added at the place where the water goes over the weir, and the turbulence below the weir provides the mixing. For small plants, a v-notch weir is more effective than a rectangular weir. A 90° v-notch weir will handle flows as shown in Table 12-2. The head loss involved in using a weir is about 0.3 m.

Table 12-2 Discharge Over a 90° V-Notch Weir

HEAD (cm)	DISCHARGE (m^3/hour)
5 (minimum)	2.9
6	4.5
8	9.4
10	16.6
12	25.9
14	38.7
16	54.0

Such a weir makes an excellent, low cost means for measuring plant flow.

Mixing can be accomplished in pipes, with mixing a function of the head loss. In general, a head loss of about 0.2 m is adequate. This can be produced with an orifice plate or other restriction in the pipe. (This restriction can also be used for flow measurement.) A simple venturi-like arrangement can be provided with a reducer and enlarger.

Flocculation

After the chemical coagulants are dispersed in the water, gentle agitation is required to cause the colloidal and suspended solids to coalesce to become particles large enough to settle in sedimentation tanks and be removed in filters.

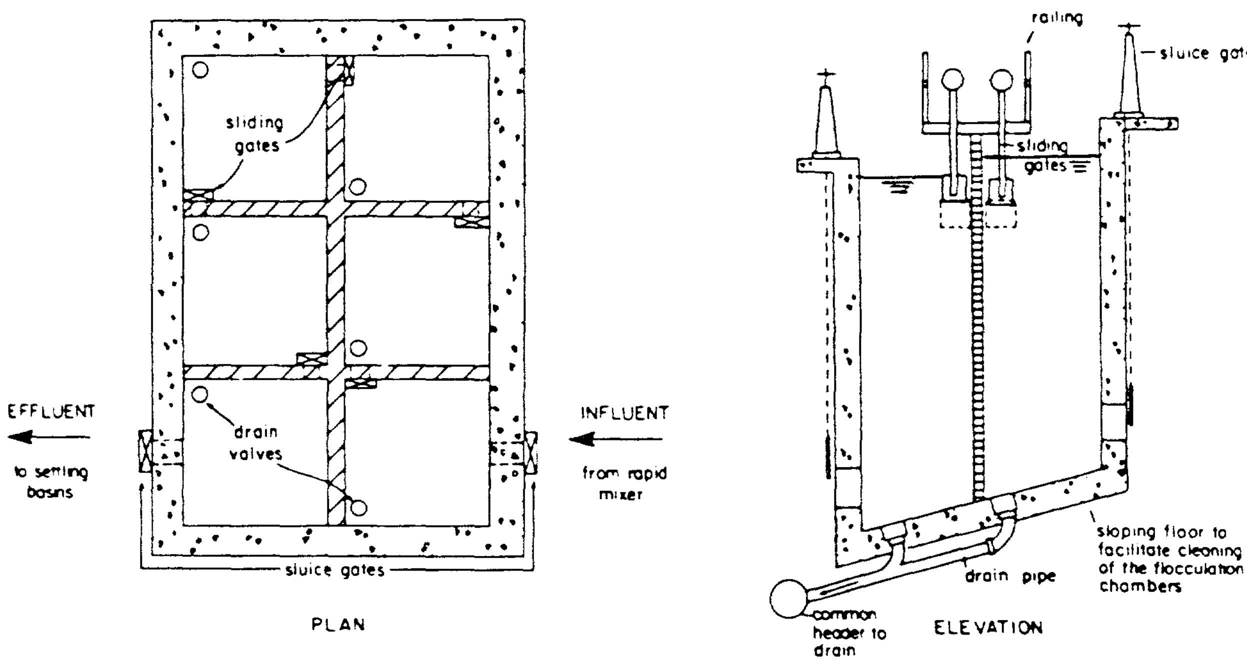
The important design criteria are the time for flocculation and the velocity gradient, and their combination. The velocity gradient is a measure of the opportunity for collision or rate of collisions between particles which produces coalescence. A measure of the velocity gradient for a tank of a given size is the power input for flocculation which, in hydraulic flocculators, is the head loss. Excessive or insufficient power input or head loss does not permit flocculation. In general, the ranges sought are detention periods of 20 to 30 minutes with head losses of about 0.5 m.

The best guides as to design are experiences with treatment of similar waters in nearby plants or the use of jar tests which can provide a rough guide as to whether the water is easy or difficult to coagulate and the time that might be required. Temperature is important, as more time is required at low temperatures.

Flocculation can be done mechanically or hydraulically. For small plants, hydraulic flocculation is preferred. One type is baffled chambers, which are low in cost because the baffles need not be water tight nor do they require much structural strength.

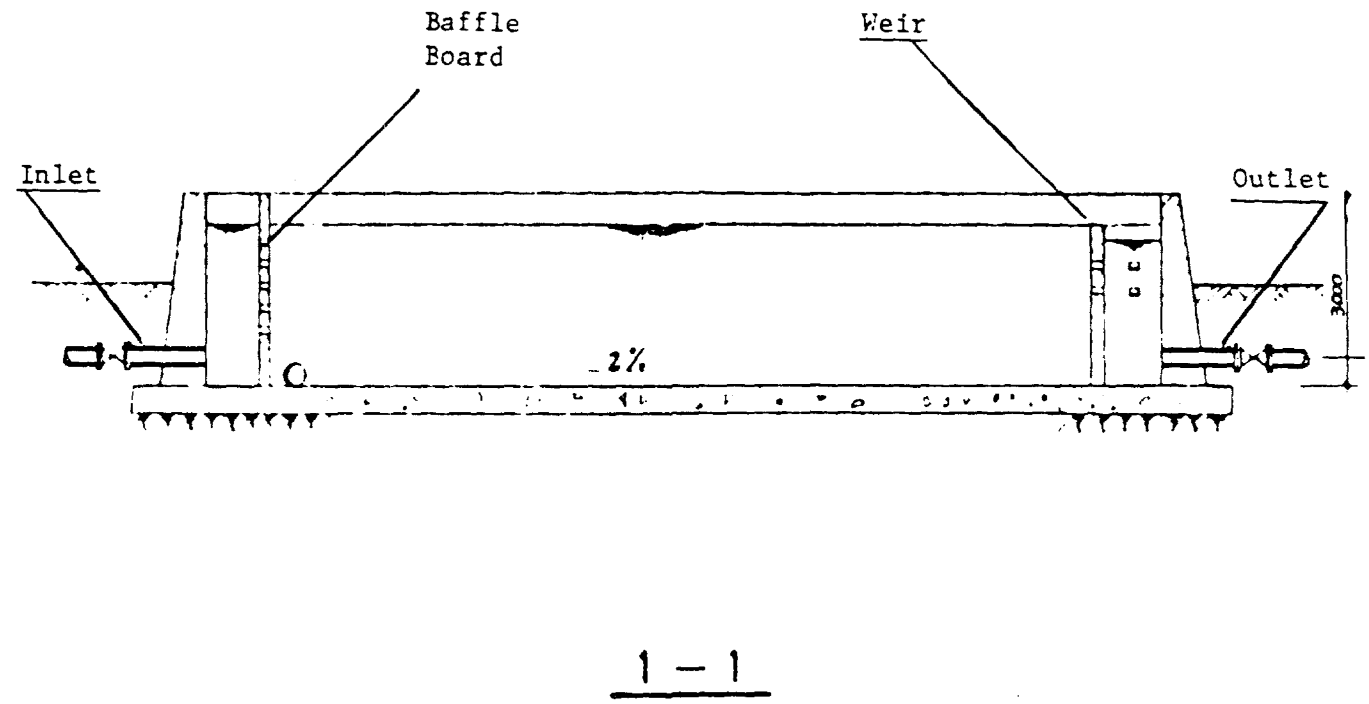
For very small plants, baffled flocculators are not convenient, and jet-action, heliocoidal flow units (Figures 12-2 and 12-4) are more suitable. The inlet pipes produce a higher velocity, up to 2 m/sec while the outlet pipe

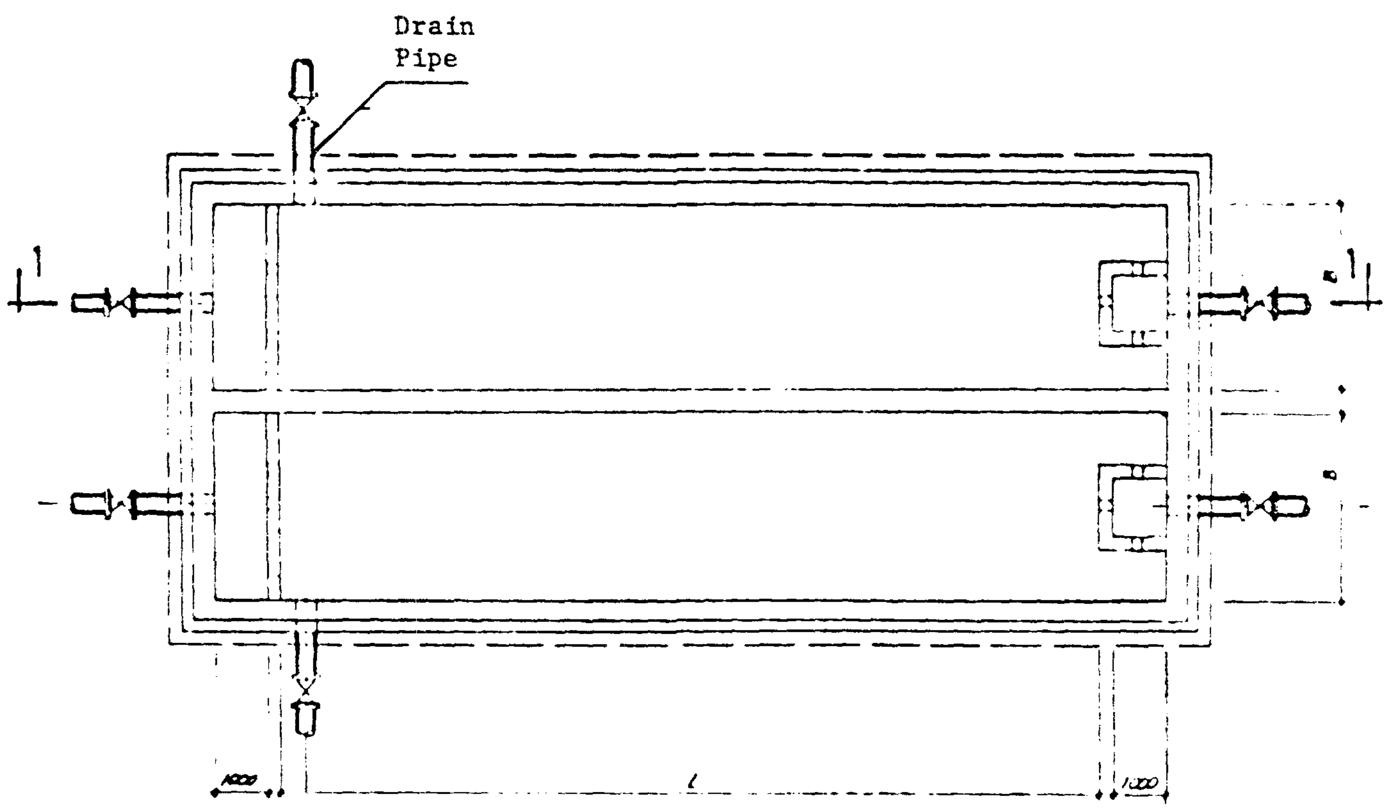
Figure 12-2 Heliocoidal-flow Flocculator



Source: Adapted from IRC (1980)

Figure 12-3 Sedimentation Basin

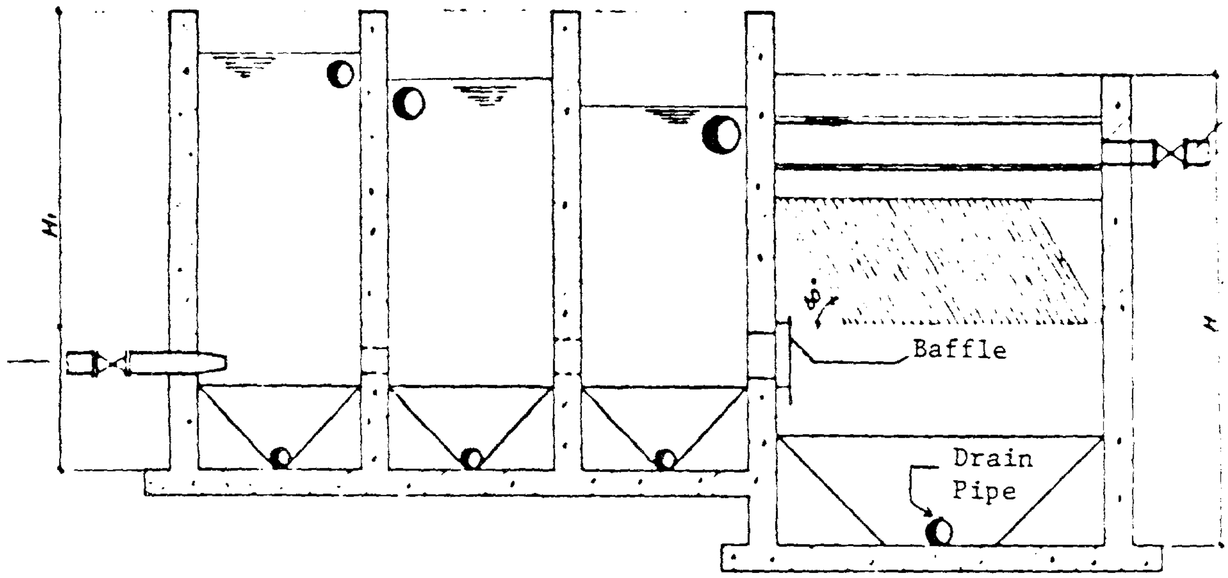




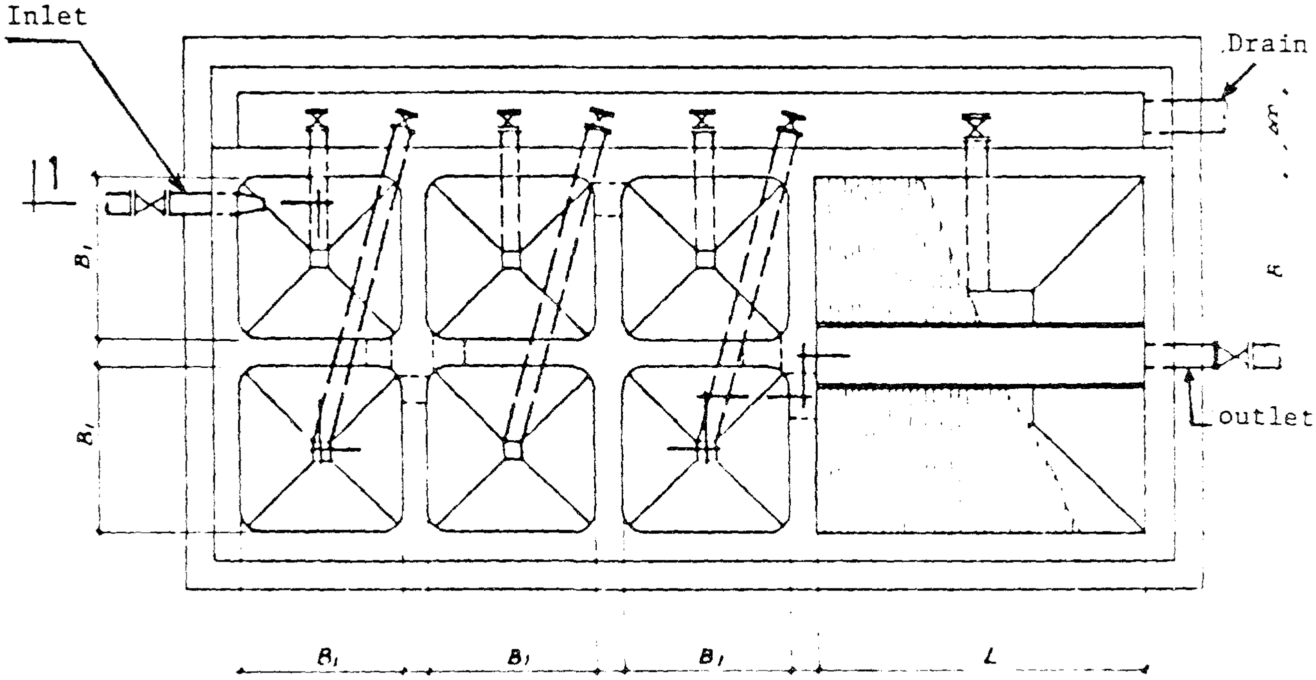
PLAN VIEW

Source: People's Republic of China (1984)

Figure 12-4 Tube Settler Sedimentation with Heliocoidal Flocculators



1 — 1



Plan View

Source: People's Republic of China (1984)

velocities leading to sedimentation tanks should be about 0.1 to 0.2 m/sec. Simple adjustable sluice gates on the openings between the units adjust the velocities in each tank should this be necessary. This can be important if the flow varies from the design flow. Sloping bottoms to a common drain save on the number of valves required.

Other types of units are available, such as gravel bed flocculators, but they offer little advantage over those mentioned.

12.7 Sedimentation

The sedimentation process is important in water treatment as it reduces the load on the filters. It is a unit with little energy requirements, low head loss and simple in construction so that it can be designed liberally at little extra cost and thereby assure better plant operation in the event of any upsets in raw water quality.

For rural treatment works, the most simple designs are the most appropriate: horizontal flow, manually cleaned units, with two in parallel so that one can be taken out of service for cleaning without interfering with plant operation. Upflow units may be warranted in large urban treatment plants where space is limited, but are not appropriate for small plants. Horizontal flow units:

- are more tolerant of shock loadings;
- are more uniform in performance;
- can handle high silt loads without upset;
- of large capacity can be provided at low cost; and
- are simple to operate and maintain.

Two design parameters are important: surface loading and detention period. For very small plants, surface loadings should be about 10 to 20 m/day, with detention periods of at least 4 hours. For a plant of 10 m^3/hr, this would require sedimentation tank capacity of at least 40 m^3, an area of at least 24 m^2, and a usable depth of about 1.7 meters. Allowing 0.3 to 0.6 m for sludge storage would call for a water depth of about 2 m.

The sedimentation basin design shown in Figure 12-3 is well suited to the rural water supply situation. A source of water under pressure for flushing and provision for draining are necessary.

The sedimentation unit shown in Figure 12-4 uses tube settlers, which permit loadings about 50% to 150% greater than without them. These can be made locally of plastic at low cost.

12.8 Filtration

Filtration is required for almost all surface waters and for groundwaters containing iron. Filtration clarifies the water and reduces the chlorine demand, producing a better bacteriological quality and better taste. The most appropriate filters for rural communities are slow or rapid sand filters.

Filtration operates by the flow of water through a bed of sand or other granular material. The particles in the water are removed by sedimentation within the pore spaces in the sand and by adsorption on the surface of the grains. The particles to be removed are smaller than the pore spaces in the sand, so they are not removed by straining. Slow sand filters, in addition, allow the development of an organic, bacteria-rich layer on the surface of the filter which provides greater removal of color, turbidity and bacteria than rapid sand filters.

Slow Sand Filters

These operate with ungraded sand, so their hydraulic capacity is much smaller than rapid sand filters. Also, most removal of impurities occurs in the upper 5 to 20 mm of the sand layer. When this layer is clogged it is scraped off and stored for cleaning. After several layers are removed, the cleaned sand is returned to the filter. The interval of time between scrapings depends on the quality of the raw water, but may be up to several months.

The biological layer removes substantial concentrations of bacteria, from 99% to 99.99%, so that it may be possible, although not recommended, to omit Bhlorination. Chlorination is always necessary with rapid sand filters.

Slow sand filters are most appropriate for treatment of low-turbidity waters, less than 50 NTU, although short periods of higher turbidity may be tolerated. In such instances, pretreatment by roughing filters may be used. Pretreatment by chemical coagulation is seldom appropriate because floc carryover quickly clogs the filter.

The advantages of slow sand filters for rural water supply systems are:

- simple construction and low construction cost;
- simple operation, requiring limited supervision and using unskilled operators;
- material requirements for equipment, pipe and chemicals are small;
- less head is required and if gravity flow is available, power is not required;
- variations in raw water quality can be tolerated;
- much less water is required for washing the sand than is required for rapid filters.

The major disadvantages are:

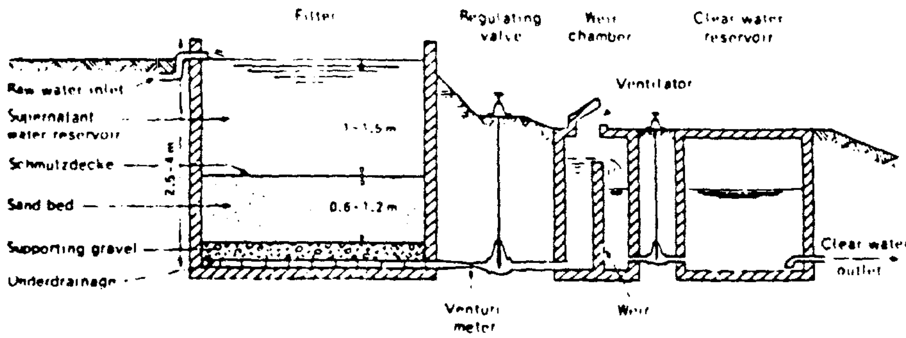
- much larger area requirements, about 5 times;
- need for covering in freezing climates;
- possibility of algae growth that may clog filters.

Design parameters for slow sand filters are:

- loading, about 0.1 to 0.2 m/hour;
- depth of bed, 1.0 to 1.2 m, to be reduced by scraping to no less than 0.6 to 0.8 m;
- filter sand 0.2 to 1.0 mm;
- head over filter, 1.0 to 1.5 m;
- the gravel which supports the underdrain system is generally comprised of 4 to 5 layers to a total depth of about 0.5 m, sized from about 0.5 mm at the top layer to about 30 mm at the bottom;
- underdrain system may be perforated pipes or stacked bricks.

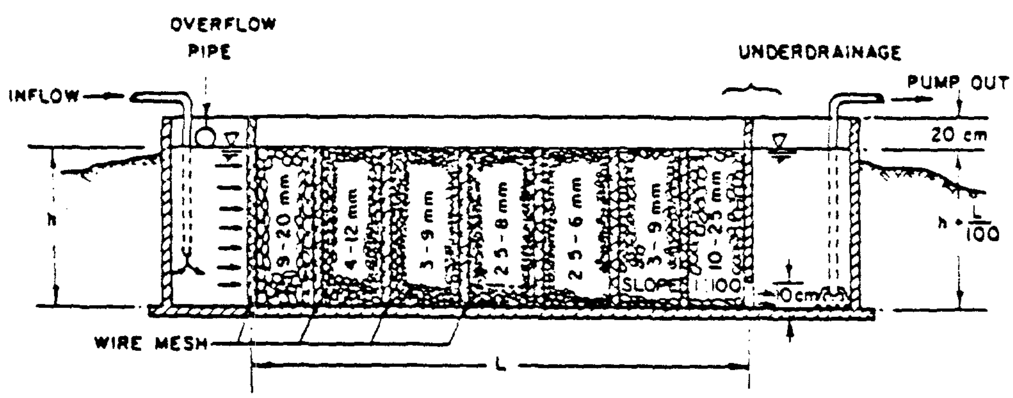
A typical design is shown in Figure 12-5. In general, at least two filters are needed, so that one can be in operation while the other is being cleaned. A normal range of head losses is from about 0.6 m when clean to about 1.2 m when dirty.

Figure 12-5 Diagram of a Slow Sand Filter



Source: Huisman and Wood (1974)

Figure 12-6 Horizontal Roughing Filter



Provision needs to be made for washing the sand after it is removed from the bed. A simple arrangement is a box large enough to hold 2 or 3 scrapings from a filter. A plant of 10 m^3/hr capacity with two 35 m^2 filters would need a box about 3.5 x 1.5 m, 0.6 m deep. Storage capacity for sand should be sufficient for about 50% of the sand on one filter.

Roughing Filters

Roughing filters are sometimes used to pretreat waters that would otherwise place too heavy a burden on slow sand filters. They are made of coarse sand or gravel and may be vertical or horizontal. Horizontal-flow units are most appropriate for rural water supplies, as they are simpler to build and to operate. Figure 12-6 shows a typical unit with 6 gravel zones, separated by wire mesh or open brick work, ranging from coarse to fine but ending up with a coarse zone. The following characteristics are typical: flow rate about 1 to 2 m/hr; depth 0.8 to 1.5 m; length to width, 3:1 to 5:1; gravel sizes, coarse 9 to 20 mm to fine 2 to 5 mm.

For a roughing filter for a plant of 10 m^3/hr capacity, at 2 m/hr loading, the width of each of two filters, 1.5 m deep, would be about 1.7 m with a length of about 8 m.

They may operate for many months without cleaning. Cleaning is done by removing the gravel by hand for washing and replacement.

12.9 Rapid Sand Filters

Rapid sand filters operate at rates substantially higher than slow sand filters, so that they require far less space and are more easily covered or enclosed, which protects them against freezing in the north and algal growths in the south. They may be gravity or pressure filters. Gravity filters are preferred because they cost less than pressure filters and can be built of local materials, concrete or brick. Pressure filters are made of steel, need to be transported to the site from the place of manufacture, and are more subject to corrosion.

Gravity filters are more easily operated and maintained, as the plant operators can observe the sand and the effectiveness of backwashing. With pressure filters, the sand might be lost and the operators would not be aware of it for some time.

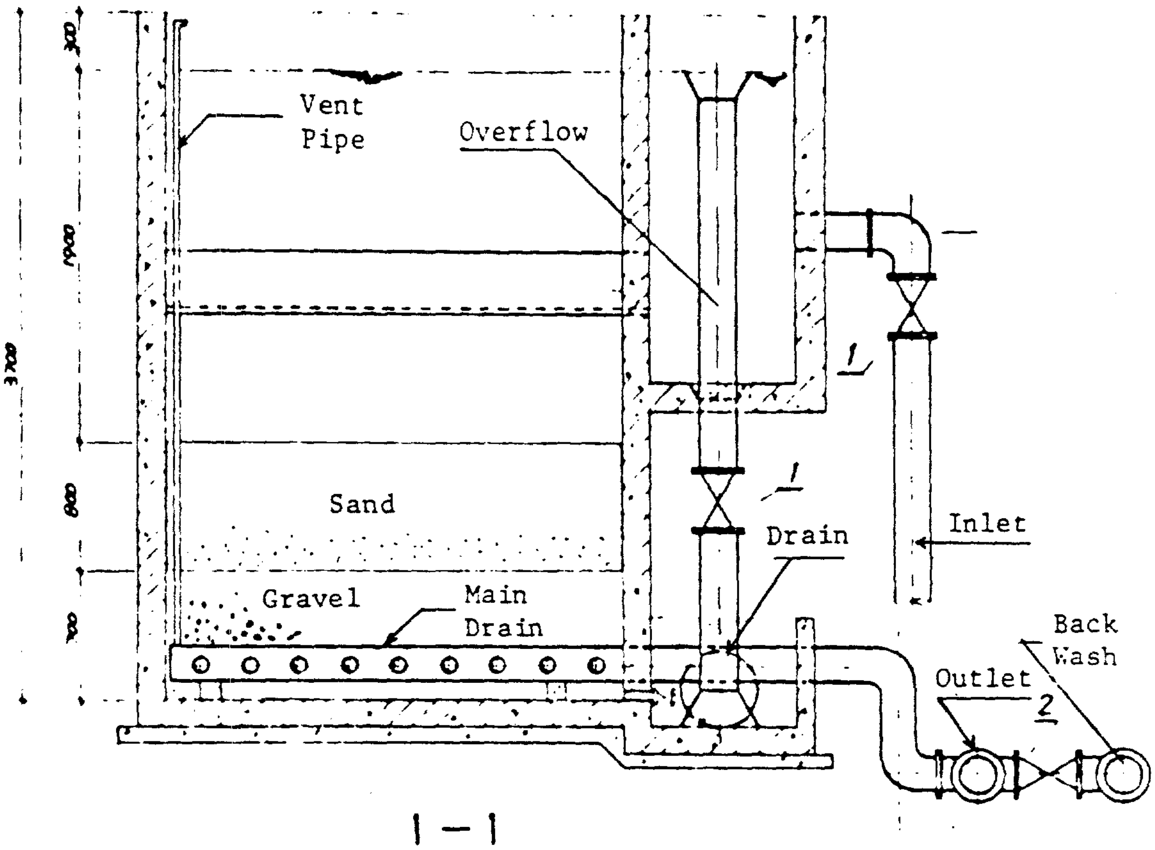
The principal advantages of pressure filters are that they eliminate the need for double-pumping and they can be installed more quickly than reinforced concrete filters can be built. However, these advantages are not sufficient to justify their use in rural communities. Pressure filters are suitable for small factories, commercial establishments, swimming pools, and similar installations.

Design Parameters for Rapid Sand Filters

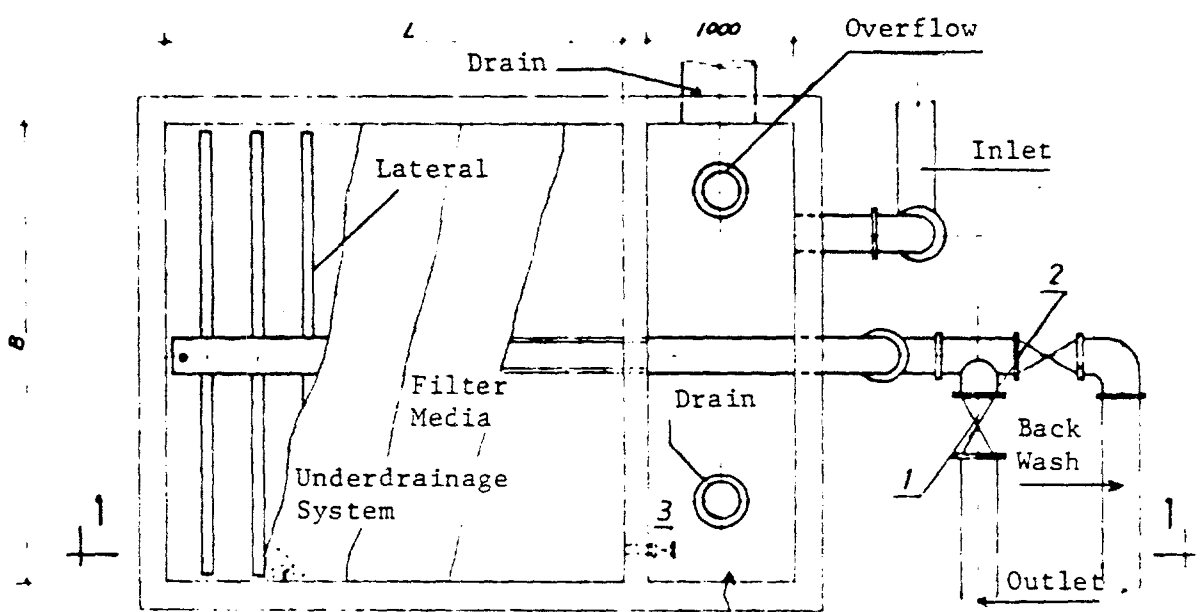
The design shown in Figure 12-7 is suitable for rural communities. Loadings of 5 m/hr are satisfactory but higher loadings may be found to be acceptable by experience. The depth of the filter is typical, 3.5 to 4 m. The head loss in filtering should not exceed 3.0 m.

At least two filters should be provided so that for a plant of 30 m^3/hr capacity, two 15 m^3/hr filters should be available.

Figure 12-7 Rapid Sand Filter



1 — 1



Plan View

Drainage

Source: People's Republic of China (1984)

The sizing of sand is important. It is best to have as uniform a sand as possible, with a non-uniformity coefficient (P_{60}/P_{10}) of 1.5 to 2.0. The effective size, P_{10}, should be about 0.5 to 0.6 mm. A source of sand needs to be identified and facilities for upgrading the sand, if not already available, may need to be established.

Flow through rapid sand filters can be controlled at the inlet or the outlet, at individual filters or for the group of filters together. A common approach for large plants is to have individual rate controllers on each filter to keep the rate constant for each filter. For small rural supplies, it is most economical and quite satisfactory to operate all the filters together with provision for taking each filter out of service separately for backwashing.

Figure 12-8 shows several flow control arrangements that are simple but satisfactory. The simplest is b, which uses an effluent overflow weir to keep the sand submerged at all times and allows the level of water in the filter to vary with the head loss. The influent flow is split equally among all the filters by an influent weir.

Another simple alternative is "declining-rate" filtration, shown in Figure 12-9. All the filters operate with the same effluent elevation, using an effluent weir set to protect the sand from being exposed. The flow through each filter varies, being highest when the filter has just been washed and lowest when it is dirty and needs to be washed. The water level in the filter rises as the filter becomes dirty. When the water level reaches its maximum, about the level in the influent channel, the filter needs to be washed.

Backwashing

Filters are cleaned by backwashing with filtered water at velocities high enough to suspend all the sand so that the accumulated floc particles can be washed off the sand grains and carried away with the washwater. The velocity, which determines the required rate of backwash, should be enough to suspend all the sand but no more, as to use more wastes water and does not improve washing. The velocity required increases with the sand size and temperature, so the design must be based upon the largest size sand in the bed and the highest water temperature expected. The wash water rate can be decreased in winter.

The following are approximate washwater rates for sands of various sizes at 10°C.

Sand Size (mm)	Velocity (m/hr)
0.4	12
0.6	22
0.8	34
1.0	47
1.2	62

Backwash velocities are 8 to 12 times greater than the filtration velocities, so that the underdrain systems are designed for backwash rather than filtration.

Figure 12-8 Filter Control Systems

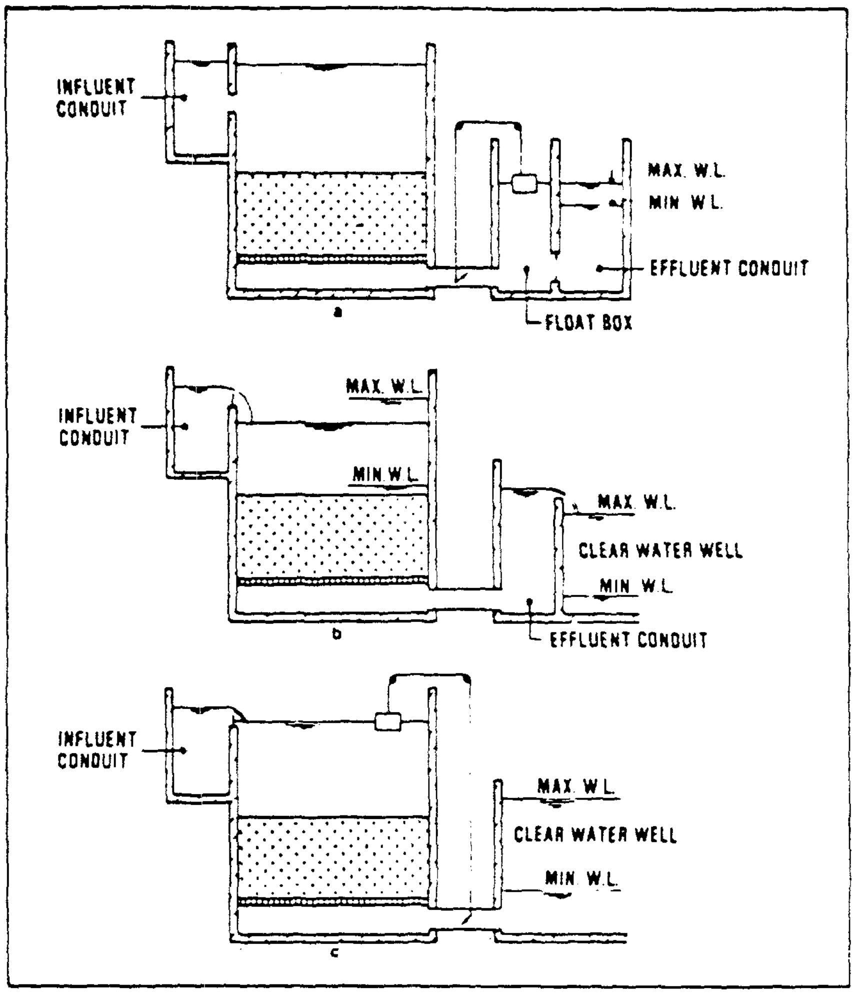
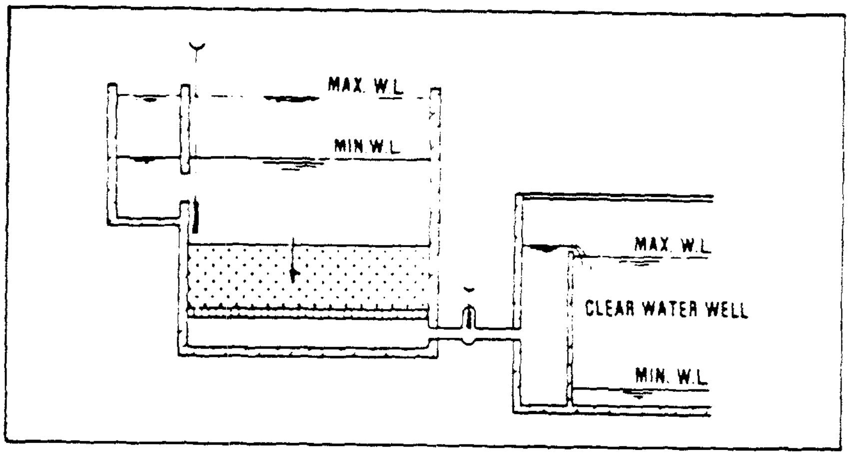


Figure 12-9 Declining-Rate Filtration



Source: Hofkes (1981)

For a 15 m^3/hr filter, with an area of 2.25 m^2, the washwater capacity would need to be about 150 m^3/hr. Methods for providing water at this rate are discussed below. Where sand sizes are larger and high backwash rates are necessary, water can be conserved by using air with water. This is widely done in Europe but is an unnecessary complication for small treatment plants, because air compressors and special underdrains are required. Surface washing, to cleanse the upper few centimeters of the bed where most of the dirt accumulates, is a common practice in large plants but not necessary in very small plants.

The head required for backwash is the sum of the head losses in the piping, the underdrain system, and in suspending the sand, measured to the lip of the washwater gutter. Ordinarily, this ranges from 4 to 6 m.

Backwash water can be provided by

- direct pumping from the clear well,
- taking water from the distribution system if the system has an elevated tank,
- using an elevated washwater tank which is filled by pumping, or
- using the effluent from operating filters to backwash the filter to be cleaned.

Direct pumping from the clear well is common in large plants but not appropriate for very small plants. In small plants, the wash water pump and the motor to drive it would have to be much larger than any other pump in the plant, and the capacity of the power supply would need to be much greater than is otherwise necessary.

If there is an elevated tank on the system, and particularly if the elevated tank is at the plant, which is convenient in rural systems, the washwater can be taken from the system. The pressure would be much greater than is necessary, but the waste in energy is small because less than 5% of the water is used for backwashing. However to avoid blowing the sand out of the filter, a constriction would need to be placed in the backwash line, or a separate smaller washwater tank could be placed at lower elevation than the distribution system service reservoir.

Where it is not possible to use water from the distribution system, an elevated tank is required. It can be filled by small pumps drawing from the clear well. This is necessary with gravity systems where the system pressure is too low to wash the filters. The elevated tank should be large enough to wash at least one filter and preferably two filters for about 8 minutes at the design rate. For the 15 m^3/hr filter mentioned before, the elevated tank would have to hold about 8 m^3. Two small pumps should be available to fill the tank. Their capacity could be 1 to 2 m^3/hr as compared with 60 m^3/hr for direct pumping.

Underdrain Systems

The underdrains are designed to collect the filtered water and to distribute the washwater so as to raise the sand evenly across the bed.

To attain good distribution, the head loss in the underdrain system during washing should be 1 to 4 m, mostly created in the orifices to establish a high controlling loss of head.

The simplest system is perforated pipes set in gravel as shown in Figure 12-7.

Useful guidelines for pipe underdrains are:

- Ratio of total area of orifices to area of filter bed: 0.0015 to 0.005;
- Ratio of cross-sectional areas of manifold to lateral: 1.5 to 3;
- Diameter of orifices: 6 to 18 mm;
- Spacing of orifices and laterals: 175 to 300 mm;
- Orifices face down, about 30° from vertical.

The gravel bed, about 0.5 to 0.7 m deep, is set in layers, with the lowest, around the laterals, being 20 to 40 mm in size, and the finest, at the top supporting the sand, being 2 to 4 mm in size.

12.10 Iron and Manganese Removal

Iron in surface waters, being associated with particulates, and well oxidized, is easily removed in conventional treatment. The greater problem is the iron and manganese content in many groundwaters, where they are in reduced form in solution. A common approach is aeration followed by filtration, often accomplished by spraying the water onto the filter. Where the iron content is high, sedimentation prior to filtration is helpful. A simple arrangement for water with low iron is aeration in a series of trays filled with stone, followed by slow sand filtration. Prechlorination can assist in manganese removal.

Where iron and manganese causes clogging of the well screens, underground treatment can be used to reduce iron and manganese to below 0.5 mg/l. Aerated water from a second well or a storage tank is injected into the well. The aerated water oxidizes the dissolved iron and manganese in the aquifer around the well, bringing it into a particulate form, which is removed by the natural filtering capacity of the aquifer.

12.11 Activated Carbon Treatment

Where waters with tastes and odors, or heavily polluted waters, must be used as a source, activated carbon filters are being considered. However, such filters are experimental and expensive, and their effectiveness is uncertain. Where such units would be required, an alternate source should be used.

12.12 Clear Wells

A treatment plant operates best at a uniform rate; it should not need to respond to hourly changes in demand. In some instances, savings may result by operating the treatment plant for one or two shifts, although the supply to the community needs to be available 24 hours per day. To allow constant-rate operation for 24 hours or for shorter periods, a clear well to store filtered water is necessary. The clear well also serves as a source of water for filter wash water and as a wet well for the pumps that discharge treated water to the community. Also, it provides chlorine contact time prior to distribution of the water.

If adequate elevated storage is available the capacity of the clear well can be small; just enough to provide water for washing the filters. If elevated storage is not available, the capacity will have to be large enough to handle hourly variations in demand. If 24-hour operation is planned, a tank capacity of about 25% of the design capacity of the plant, the maximum day demand, would be satisfactory. If it is to operate for an 8-hour shift, the tank should be about 50% of the design capacity. Accordingly, for a plant of 10 m^3/hr capacity, the clear well should hold from 60 to 120 m^3.

12.13 High-lift Pumping

The pumps that deliver the treated water to the community are generally housed in the treatment plant. Pump selection is discussed in Chapter 8 and the head requirements are discussed in Chapter 11. Where adequate elevated storage is available to provide for hourly variations in demand, the high-lift pumps are the same discharge capacity as the low-lift pumps, enough for the maximum day. Without elevated storage, the pumps must be sized for the peak hour.

At least two pumps must be available, each of adequate capacity operating alone, so that one is available for standby. They should be operated alternately.

Where a history of power failures is present, either a diesel or petrol motor should be made available to drive the pumps or to drive electricity generators to operate the pumps.

12.14 Service Building

The service building must provide space for the following:

- Plant office, with files for storing records;
- Laboratory, for control tests;
- Storage for spare parts for equipment, chemicals, service meters, valves, fittings, and other supplies, and a locker room for personnel;
- If another office for system operations and customer contact is not provided in the community, it can be provided at the plant;
- Switch gear; and
- Pumps.

The service building is often the most visible element of the water system. The community will be more inclined to have confidence in the system if they see that this facility is well-designed and maintained. A meeting room for visitors is desirable and school children should find a visit to the water treatment plant a rewarding educational experience.

Chapter 13

Sanitation and Wastewater Collection and Disposal

13.1 Existing Sanitation Facilities

The problems of human excreta and domestic wastewater disposal in a rural community can be expected to change when a new water supply is introduced. Also, waste disposal practices in commercial, industrial and institutional facilities can be expected to be affected. The impact of a new water supply on sanitation depends on the level of water service and on the system of sanitation in use.

Most communities without a piped water system will have some type of latrine system. Where the water supply is to be from hand pumps in shallow wells or roof catchments, the impact will be considerably less than where the new water supply is to provide piped water to a kitchen, toilet and bath within the house. Figure 13-1 provides an overview of common sanitation and waste disposal systems.

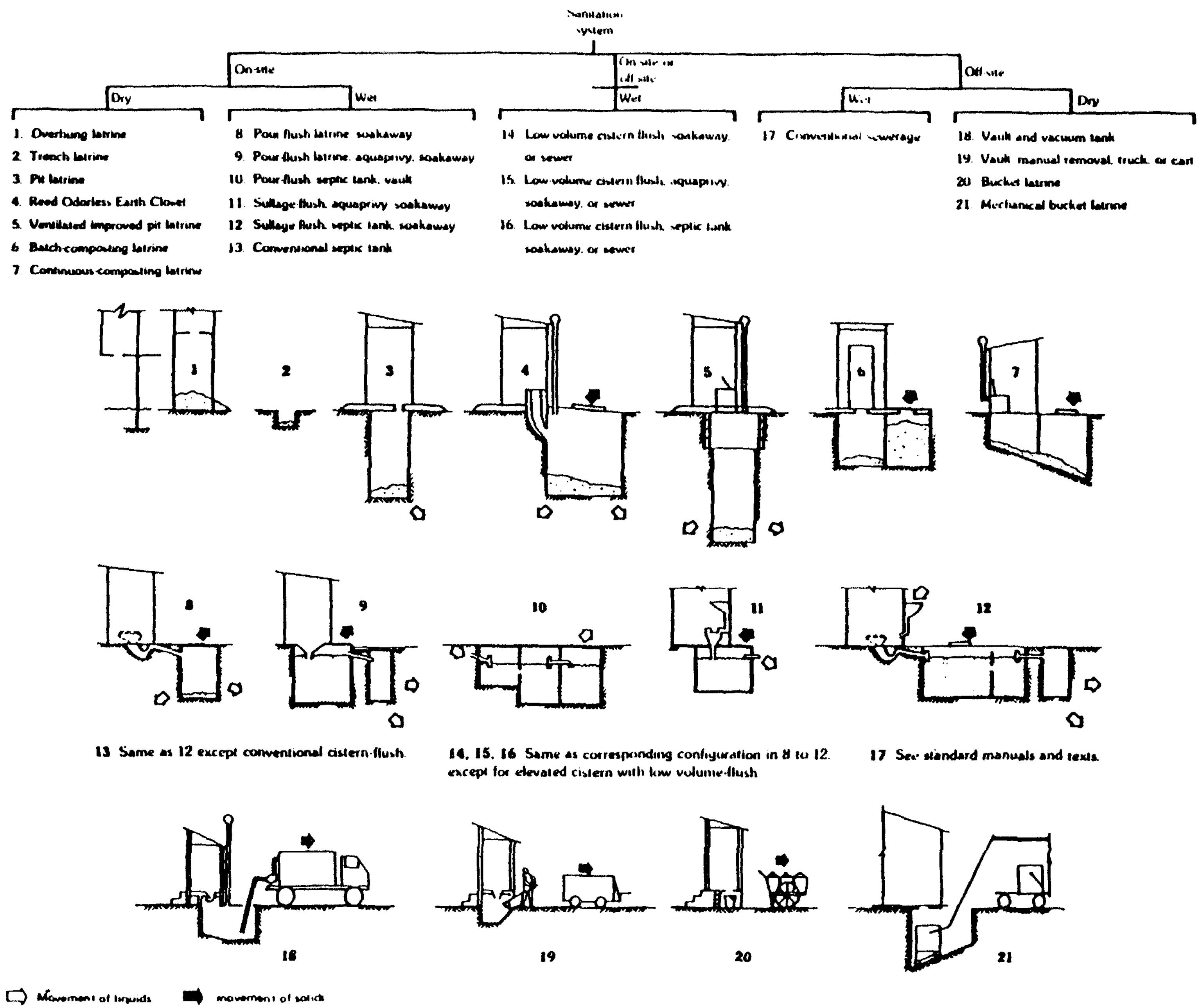
Impact of Handpumps, Roof Catchments and Public Standposts
Such supplies are not likely to change the methods of waste disposal, but they will increase the amounts of water available for cleansing in homes, requiring increased sullage disposal. Sullage can be collected and used for watering or allowed to soak into the ground.

Impact of Piped Supplies with House Connections
Piped water to the house increases per capita usage and requires some type of plumbing to carry away used water from kitchen sinks, baths and toilets. Where toilets are not provided, the problem remains much the same as described for the disposal of the sullage water, although the amount will be much greater and the drainage system will need to be more elaborate. Piping from the sink drains and floor drains leading to a soakage pit may be satisfactory. If the density of population is high, it may be advisable to collect the sullage from all the houses in a compound and conduct the sullage water to a simple disposal tank or treatment system. The wastewater can be reclaimed for irrigation in the dry season, but provision needs to be made for its disposal in the wet season.

The problem is considerably greater where toilets are installed. So-called "pour-flush toilets", where the toilet is flushed by hand with water poured from a bucket, use less water than conventional toilets, about 3 to 6 liters per capita. Such toilets can discharge into vaults with porous sides or bottoms, which allow the liquid portion to soak away. They can also discharge into tight vaults, where the solid material accumulates in the vault and the liquid overflows into a soakage pit or some other disposal facility, even to small-bore sewers. The solid materials must be pumped out of the vaults periodically and disposed of safely. They can be used on fields, but have poorer fertilizer value than night soil from dry vaults.

Conventional flush toilets create the greatest problem, as the amounts of water used per capita for toilet-flushing are much greater, calling for 10 to 20 liters per flush. Where the density of housing is great, individual systems for disposal are not feasible and a sewerage system is required. In such instances, the wastewaters from sinks, baths and other water-using

Figure 13-1 Generic Classification of Sanitation Systems



fixtures are most conveniently combined with toilet waters. Where ample space is available, individual household systems, such as septic tanks which discharge into the ground, may be economical.

Institutional, Commercial and Industrial Wastewaters

Where piped water serves institutions, such as schools and clinics, commercial establishments, such as laundries, or industries, large volumes of wastewaters need to be handled. Each such situation is special and regulations for wastewater collection and disposal are required.

13.2 Impact of Sanitation and Waste Disposal on Water Supply

If a high level of water service is to be considered, estimates of the costs of wastewater collection, treatment and disposal cannot be ignored.

The construction costs for even the simplest water-carried waste disposal system can often be more per household or per capita than providing the water supply itself. Tables 13-1 and 13-2 provide very approximate cost data for the investment and recurrent expenditures per household for waste disposal.

The necessity for sanitary disposal of wastewaters following the introduction of water supply into homes and the adoption of water-carried waste disposal may very well affect the affordability of the water supply system. Public health engineers have long maintained that planning for water supply must include the accompanying need for waste disposal but experience has been that water supplies are introduced first, serious problems are created, and only then is waste disposal considered.

If financial resources are limited, the introduction of water-carried waste disposal systems should be delayed: the initial water supply should not then consider providing water for flush-toilet systems. For this reason, this manual does not illustrate systems that would require sewerage.

In addition to the impacts of water supply on the amount of wastewater to be handled and thereby the required waste disposal facilities, the introduction of new sanitation facilities can significantly influence the demand for water. This is especially true if sewer systems are introduced because large quantities of water (usually more than 200 liter per capita per day) are required to operate a sewer system.

However, even improvements from dry latrines to pour-flush systems tend to increase the water demand by up to 10 liters per capita per day. The introduction of pour-flush toilets may also increase the demand for yard and house connections which, if installed, may increase the demand much further.

Sanitation facilities, wastewater and solid waste disposal may pose considerable risks to the quality of the available water resources. Seepage from latrines, septic tanks, defective wastewater pipes and sewers can contaminate groundwater. This problem needs special attention if: (i) the groundwater level is high or tends to become high during the rainy season; (ii) the leakage may reach the ground water very easily due to high soil permeability or fine cracks in the rock; (iii) shallow wells or springs are located relatively close to sanitation facilities; or (iv) house and yard connections are installed in relatively densely populated areas.

Table 13-1 Average Annual On-site, Waste Collection, and Treatment Costs per Household (1978 U.S. dollars)

Facility	On-site Costs	Collection Costs	Treatment Costs	
Low cost				
Pour-foush toilet		18.7	-	-
Pit privy		28.5	-	-
Coommunal toilet	34.0	-	-	
Vacuum-truck cartage	16.8	14.0	6.6	
Low-cost septic tanks	51.6	-	-	
Composting toilets	47.0	-	8.0	
Bucket cartage *	32.9	26.0	6.0	
Medium cost				
Sewered aquaprivy *	89.8	39.2	30.2	
Aquaprivy		168.0	-	-
Japanese vacuum truck	128.0	34.0	26.0	
High cost				
Septic tanks	332.3	25.6	11.3	
Sewerage		201.6	82.8	115.9

* To account for large differences in the number of users, per capita costs were calculated based on six persons per household.

Source: World Bank (1980)

Table 13-2 Financial Requirements for Investment and Recurrent Costs for Sanitation per Household (1978 U.S. dollars)

Facility	Total Investment Cost	Monthly Recurrent Cost	Hypothetical Total Monthly Cost a/	Percent of average low-income household b/
Low cost				
Pour-flush toilet	70.7	0.5	2.0	2
Pit latrine	123.0	-	2.6	3
Communal facility a/	355.2	0.9	8.3	9
Vacuum truck cartage	107.3	1.6	3.8	4
Low-cost septic tanks	204.5	0.9	5.2	6
Composting latrine	397.7	0.4	8.7	10
Bucket cartage b/	192.2	2.3	6.3	7
Medium cost				
Sewered aquaprivy	570.4	2.9	10.0	11
Aquaprivy	1,100.4	0.5	14.2	16
Japanese cartage	709.9	5.0	13.8	15
High cost				
Septic tanks	1,645.0	11.8	25.8	29
Sewerage (design population)	1,478.6	10.8	23.4	26

a/ Assuming 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/ Assuming average annual income per capita of $180 and six persons per household.

Source: World Bank (1980)

The drainage of wastewater into rivers and lakes may also: (i) greatly reduce the quality of these waters as a drinking water source, (ii) cause nuisance by odors resulting from high wastewater loads, or (iii) result in fish kills from oxygen depletion of the water if large quanitites of wastewater are discharged into small rivers or lakes.

Inadequate sanitation and waste disposal, and the resulting contamination of groundwater and surface water, may greatly reduce or foil the expected health benefits of water supply projects.

The consequences of improved water supply on sanitation and waste disposal and the expected health benefits should be assessed and evaluated for each individual project or community. The need and resulting costs of required sanitation and wastewater disposal measures must be evaluated and be included in feasibility analysis of water supply projects.

Chapter 14

Operation and Maintenance

Inadequate concern for operation and maintenance (O&M) during the planning stage is a major factor contributing to early system failures and rapid deterioration encountered in many rural water supply projects. O&M should receive attention during the project planning process. This chapter provides an overview of factors affecting O&M, and identifies the information which should be provided in a separate operation and maintenance manual.

14.1 Relevant Planning

O&M costs, as well as costs of all necessary supportive components provided at a regional or national level (such as training and technical assistance, procurement, storage and distribution of materials, etc.), must be part of planning. Chapter 15 covers O&M costs.

Commitments to recover at least annual O&M costs (and preferably capital costs as well) must be planned from the outset. While preferably accomplished either by local community contributions or water tariffs, governmental subsidies or indirect subsidies through participation in regional water districts (which include more economically secure communities) may need to be provided.

Recovering O&M costs is often the most critical problem to be met in ensuring continued functioning of the system. Factors which tend to improve the commitment to support a local water supply include:

(i) promotion and creation of a local water committee or board to act as the responsible executive body, and strong community involvement during all planning stages;

(ii) involvement of women in local committees, since they tend to receive the most benefits from improved water supply;

(iii) metering of all house connections, which usually improves user satisfaction and willingness to pay; and

(iv) continuous provision of an acceptable level of service.

Related financial and economic factors are discussed in Chapter 15 and institutional issues in Chapter 18.

14.2 Preventive Maintenance

Preventive maintenance, involving systematic and periodic maintenance procedures for all major system components, minimizes break-downs, increases efficiency and prolongs the life of the system. It is a continuous, planned procedure which initiates preventive actions before serious problems or break-downs occur. Such practices (i) increase user satisfaction and willingness to pay, (ii) guarantee and increase economic benefits from agricultural or commercial use of water, and (iii) improve the potential for health benefits.

The elements of preventive maintenance include:

- Inventories and record keeping: A recorded inventory of all components of the system is the basis for preventive maintenance.

For all facilities and equipment (such as wells, reservoirs, treatment plants or pumps), a card or file index system should provide all relevant technical information, and serve as a record for all maintenance or repair work carried out.

- Location maps: For the distribution network, continuously updated layout drawings of the system are needed to indicate the location of all major facilities and structures, trunk mains, pressure zones, etc., as well as detailed maps which show the location of all pipes, valves, hydrants, house connections and other relevant installations. Standardized symbols are used to distinguish the various facilities (wells, reservoirs, etc.) and the various network components (such as valves, hydrants or special fittings).
- Maintenance check lists should be developed which specify: (i) all maintenance tasks which have to be carried out, (ii) the time interval between the tasks, and (iii) materials and equipment required for maintenance. These checklists are best developed in cooperation with the supplier or manufacturer based on their instruction manuals (see next section).

The checklists are the basis for a systematic maintenance program or schedule for the system, which indicates who is responsible for the tasks defined by the checklists and when each task is to be carried out. For small systems, the responsibility for more complicated tasks may be shared with regional or district staff trained and equipped to carry out such tasks.

- Operation and maintenance manuals and instructions: In addition to the checklists and maintenance schedule, a general O&M manual should be developed which provides all required technical information to operate and maintain all components of the system. Manufacturers or suppliers of equipment, such as large pumps, power generators or treatment facilities, should be requested to supply clear instructions, and provide training and technical support during the start-up period, or whenever required.

Preventive maintenance also requires proper training, motivation, support and supervision by responsible personnel. Regular inspections are essential for the success of preventive maintenance programs.

Training efforts should ensure that O&M staff are familiar with the function, design, operation and relevant technical information of all facilities. Staff for new systems should be employed, trained and assigned to the system at the latest during the final stages of construction. Manuals and maintenance checklists should be developed in time to be used and evaluated during training sessions. If possible such training sessions should be carried out by the same institutions and personnel that will later support the local systems and their staff. Planning for training for O&M needs to begin at the inception of planning for the project.

14.3 Control of Unaccounted-for Water and Wastage

Unaccounted-for water represents the difference between the measured produced water and the metered water used. It includes: (i) leakage losses from service reservoirs, distribution pipelines, house connections, valves, hydrants, etc.; (ii) unauthorized use from hydrants or illegal connections; (iii) unmetered public use for fire fighting, street washing, construction, public buildings, etc.; (iv) meter failures, under-reading of user meters, and failure to read meters; and (v) unmetered residential or commercial use. In unmetered, or partly metered, systems unaccounted for water is not necessarily wasted water.

High levels of unaccounted-for water, up to 50 percent and more, are common in many developing countries (Dangerfield, 1983; and Estrada, 1983). Leakage generally is responsible for the major portion, followed by illegal tapping, public use, and meter under-reading and meter-failure. High levels of unaccounted-for water therefore usually indicate inadequate maintenance. Planning to minimize unaccounted for water must begin during the planning period and be continued during design, construction, and O&M phases.

High rates of wastage, including especially leakage, reduce pressures in outlying areas of a distribution system. To maintain pressures, the system pressure is then increased, resulting in further increasing leakage. Production costs increase while less water reaches the users and receipts are reduced. The problem is aggravated by consumer dissatisfaction over unreliable or intermittent supply, resulting in less willingness to pay.

The local significance of unaccounted for water depends also on: (i) the cost of water production and distribution, (ii) the marginal cost of an increase in production (the cost of water from new production facilities); and (iii) the expected level of increase in water demand.

Table 14-1 estimates the value of water lost per connection for two levels of service and a range of water production costs or water prices (Deer, 1985). This table indicates the range of feasible investments for control of leakage.

Table 14-1 Value of Water Lost per Connection

Flow:

a) Standpost:

20 l/cap-day x 50 persons/standpost = 1,000 l/day per standpost

b) House Connection:

200 l/cap-day x 5 persons/house = 1,000 l/day per house connection

Water Loss % of Total Production	WATER Amount Produced l/day	Amount Lost l/day	@ $0.10/m^3$ 1st yr.	NPW* 3 yrs.	NPW 5 yrs.	@ $1.00/m^3$ 1st yr.	NPW 3 yrs.	NPW 5 yrs.
20%	1250	250	9.10	22.6	34.50	91.20	227.00	346.00
30%	1429	429	15.70	39.00	59.50	157.00	390.00	595.00
40%	1667	667	24.30	60.40	92.10	243.00	604.00	921.00
50%	2000	1000	36.50	90.80	138.00	365.00	908.00	1380.00

Discount Rate: 10%

*NPW: Net Present Worth -- represents the discounted value of water lost over 3 and 5 years (Chapter 15).

Control Measures

Planning factors which may influence the level of unaccounted-for water and possible control measures:

<u>Under-reading or failure of meters</u> may be caused by: (i) inappropriate meter size; (ii) poor quality meters; (iii) water quality problems such as high hardness, turbidity, iron and/or manganese content, which may result in

clogging of meters; and (iv) inadequate testing and maintenance of meters. These problems stem from poor organization for meter reading, billing, revenue collection, and unauthorized use of water.

Measures in planning to control these problems include proper meter selection, improvement and maintenance of pressure, good water quality, and meter testing and maintenance.

This in turn requires improved administrative organization and consumer relations, penalties for unauthorized use and illegal connections, and enforcement by thorough inspection programs.

Leakage: The major causes of leakage in the transmission mains and the distribution system are: (i) Corrosion of pipes due to aggressive soil conditions externally, and to corrosive water internally; (ii) mechanical failure of pipes; (iii) improper design; (iv) production faults and low quality of pipe material, fittings, valves, hydrants, etc.; (v) improper handling and storage of these materials (such as careless off-loading from trucks, failure to protect plastic pipes from exposure to sun and heat); and (vi) improper installation, such as careless bending and joining of pipes, insufficient compaction of backfill, etc..

Leakage Surveys and Control

The feasibility of various leakage control and survey methods is influenced by planning decisions. Network layout (Yassuda et al., 1982) and district metering allow the detection of unexpected increases in water flow which may be caused by increased leakage (or illegal connections). The system is divided into districts which can be isolated from the rest of the network by valves. Meters placed either permanently or for special study to measure the flow into each district permit monitoring for leakage.

System pressure reduction in zones with high pressure is an efficient way to reduce leakage (NWC, 1980). High pressure in communities with varying elevation can be avoided through the use of two or more pressure zones.

Standards for pipe materials, pipeline design and pipe installation should be developed to ensure material quality and proper pipeline design and construction. Design standards should include specifications for minimum pipeline depths, thrust blocks, and valve location. Installation standards should ensure proper pipe bedding, backfilling, and testing of installed pipelines.

Plumbing codes should be introduced and enforced to reduce leakage, cross-connections, and to ensure easy access to meters and shut-off valves.

Metering at the source and at treatment plants and pumping stations, as well as metering of user connections, is necessary to estimate unaccounted-for water, including waste, and to permit calculation of unit consumption, unit cost, etc. User metering encourages water conservation by consumers and increases their willingness to pay. If all household users cannot be metered, efforts should be made to meter at least all large consumers.

14.4 Required Facilities and Equipment

Facilities for O&M that need to be provided with the water supply facilities include structures for an office, laboratory bench, locker room, shops, and possibly housing. The following are also required: office equipment, sampling and laboratory equipment, lockers, tools, vehicles, and safety equipment. The facilities and their equipment are considered together. For many small systems, such as gravity-fed spring supplies, or well systems with little treatment, the facilities required are minimal.

Offices

Office space may need to be provided for the manager of the system and the chief operator of the treatment plant, if there is a treatment plant. If the plant is convenient to the community, all of the office functions can be combined in one facility. Otherwise, an office may be provided in the community, perhaps integrated with offices for other community services. The office would be for:

- handling customer relations, including meter reading and billing,
- the assignment of distribution system tasks such as repair and extensions,
- staff relations,
- community relations, including community education, and
- financial affairs of the system.

Where a treatment plant is necessary and is away from the community, it may need a separate, smaller office for collecting, storing and reporting data on one or more of the following:

- water quantity; influent, effluent, and water used in treatment,
- water quality: influent, effluent, and in distribution system,
- chemicals used,
- power consumption,
- personnel data,
- plant logs,
- vehicle operations, and
- staff housing.

Plans and drawings of the system should be on file, and readily available for routine operations and for emergency. Provision should be made for mounting plans and drawings for permanent display.

Laboratories

Water supply laboratories, which are generally necessary only where treatment plants are provided, serve two general purposes:

(1) To provide the operator with data on plant operations to permit adjustments in treatment as the raw water quality changes. For this, a small operating control lab, often part of the office or pumping station at the treatment plant, is adequate.

(2) To prepare a record of raw and finished water quality to establish whether the finished water meets the standards and to provide information upon which system modifications or additions can be made. For this, a larger lab is necessary and can be located centrally to serve several systems.

The <u>operating control laboratory</u> must be at the treatment plant and need be equipped with only the sampling vessels and instruments for the simplest routine testing. The specific facilities depend upon the control tests to be run.

For plants with chlorination alone: chlorine residual, pH, temperature, turbidity, and color.

For conventional treatment of surface waters, all of the above plus aluminum or iron residual, depending upon coagulant used, jar test equipment, and filter kit.

Monitoring Laboratory

A monitoring lab for water quality, including bacterial and chemical contaminants, is not appropriate for a small water supply system because it is not likely that the operators could perform the tests and interpret the results adequately. The monitoring lab can be central to serve several small systems, or possibly at a seat of regional government, or at a large municipal plant that does such tests routinely for itself and can handle monitoring for nearby communities with little difficulty. The fitting of such a laboratory is not generally the responsibility of the rural water supply system.

Shops and Garages

Where the community does not provide repair shop services and garaging for vehicles, if the water system requires them, they can be provided at the treatment plant or in the community. The repair shop should include mechanic, plumbing, carpentry, and electrical tools so that routine maintenance on the water system facilities and equipment, including vehicles, can be done by water system personnel. Provision should be made for storing spare parts and other materials needed routinely. The community may have central facilities for repair and maintenance that can provide for the water system as well.

Meter repair and replacement should be done routinely on a time schedule; not only when a meter is found to be inoperative. Meter testing benches are useful for testing many meters simultaneously by running water through them in series and measuring the water in a collecting reservoir. Meter testing and repair may be done more economically at a central facility, serving several small systems.

Housing for water system personnel provides around-the-clock security. If personnel live on site, they can be more responsive. In addition, housing is a valuable perrequisite that can help attract better quality personnel.

14.5 Operation and Maintenance Manual

Those who prepare the plans for a water system should also be responsible for the preparation of a manual for operation and maintenance for that system. It should be available when the system is to go into operation.

This manual should describe all the routine operational tasks both for system management and treatment plant operation. Valves and equipment need to be identified and labeled in the manual with instructions for their operation described in accordance with various operation modes and various emergencies. The manual should provide simple, clearly understood instructions in the local language and be supported by illustrative drawings.

The format of the O&M manual can be standardized for all similar systems, but each manual needs to be made to fit the specific system for which it is designed. The instruction manual can be used in the training of facilities personnel.

Chapter 15

Economic and Financial Considerations

This chapter provides information on methods of conducting economic and financial analyses for rural water supply projects.

15.1 Selecting Least-Cost Alternatives

The purpose of least-cost analysis is to ensure that the proposed system provides the desired service at lowest cost, including both capital and operation and maintenance (O&M) costs. All feasible alternatives for achieving the results are examined. The specific capital and O&M costs can be estimated and displayed in cost streams. The costs occur over a period of years and, because units of money spent at different points in time have different values, it is necessary to bring expenditures at different times to values at a common time point, the so-called "present value" or "present worth" concept, before they can be compared for various alternatives. This can be achieved by "discounting".

Discounting

Calculations for discounting use the following formula:

$$S = P(1+i)^n$$

where S = future value, P = present worth, i = interest rate expressed as decimal, and n = number of years.

The process of converting costs into present worth is expressed by the following formula:

$$P = S\ (PWF)$$

where

PWF = present worth factor = $[1/(1+i)^n]$.

Similarly, the present worth (P) of a series of equal O&M costs can be expressed by the following formula:

$$P = R\ (SPWF)$$

where SPWF = series present worth factor, and R = equal annual cost.

Values of these factors are given in Annex 7 for i = 10%.

Present Worth Method

Converting all costs of project alternatives to their present worth costs permits comparing alternatives.

The calculation of the present worth is illustrated in Table 15-1 where operation costs increase over the first five years.

The use of present worth calculations is illustrated in Table 15-2 where two alternatives are compared. A is a pumped water system with low capital and high O&M cost, while B is a gravity-flow system with higher capital but lower O&M cost. The total investment in funds for the pumped system is greater over the first 10 years than the gravity system, and becomes increasingly greater with time; particularly as the diesel engine and pump have to be replaced sooner than the pipe. On the other hand, considering the present worth of the two alternatives, if the discount rate is high, about 10% or greater, the pumped scheme will appear to be more economical. If the discount rate is lower, the gravity system will be more economical. The importance of discount rate is clear from Table 15-2. The life of a project has the same impact. A longer period for repayment reduces the cost of a capital-intensive project as compared with a project with relatively higher O&M costs.

Table 15-1 Present Worth Estimates - Changing O&M Costs

Year	Capital Cost	Operation & Maintenance Cost	Present Worth Factor	Present Worth (i = .10)
1	100,000		1.0	100,000
2	100,000		0.91	91,000
3		6,000	0.83	5,000
4		7,000	0.75	5,200
5		8,000	0.68	5,400
6		9,000	0.62	5,600
7-31		10,000 ea. yr.	(9.48-3.79)*	56,900
TOTAL	200,000	290,000		
TOTAL (Capital+O&M)		490,000		269,100

* The series present worth factor at year 31 minus the series present worth factor at year 5.

Table 15-2 Comparison of Two Alternatives, 10-Year Life, with Varying Discount Rate

	Diesel Pumped Scheme (A)		Piped Gravity-flow Scheme (B)	
Year	Capital	Operation & Maintenance	Capital	Operation & Maintenance
1	10,000	2,500	22,000	-
2		2,500		250
3		2,500		250
4		2,500		250
5		2,500		250
6		2,500		250
7		2,500		250
8		2,500		250
9		2,500		250
10		2,500		250
		22,500		2,250

Total-10 Yr. Investment:	32,500	Total 10-Yr Investment: 24,250
Present Worth:		
@ 5%	26,900	23,700
@ 10%	23,100	23,300
@ 15%	20,400	23,000

Factors Other than Costs

Although the principal factor for comparing alternatives is costs, other important factors may not be quantifiable, yet should be taken into account. Table 15-3 presents factors that may be decisive in selection between two alternatives. The closer alternative costs are to each other, the more important non-quantifiable factors become. Given uncertainties of cost estimatres, discount rates and project life, differences of less than 10% may not be significant. Examples of non-quantifiable factors are:

- Reliability: A gravity system is inherently more reliable, and hence preferable to a pumped system because it (i) operates without pumps and with fewer mechanical and electrical parts which can fail; (ii) operates without fuel and its associated logistic problems; (iii) does not require electric power, which may itself be unreliable; and (iv) requires less maintenance and fewer skilled people. It is not feasible to estimate the costs of a pumped system that would be entirely as reliable as a gravity system.
- Water Quality: A water source of better quality (such as ground water) is preferable to a water source of lower quality (such as pond or river water which requires more elaborate treatment) and because treatment (i) is not always reliable; (ii) may not always remove tastes and odors or undetected contaminants; and (iii) requires more personnel with higher skills.
- Availability of Materials: A system that does not depend upon importation of spare parts or chemicals from abroad or from long distances is to be preferred, even if costs appear somewhat greater.

Table 15-3 Factors Other Than Costs to be Considered in Evaluating Alternatives

Feature	Alternative A	Alternative B
Water source	Spring, gravity supply	River, pumped supply
Water quality	High	Poor
Water treatment	Chlorination only	Sedimentation, filtration, chlorination
Reliability	Highly reliable	Moderately reliable
Water quantity	Spring may not be adequate in dry periods	Water supply more likely to be adequate
Personnel	Minimum skills required	Moderate to high skills required
Other factors	Water will taste uniformly good	Taste may vary with season
	Minimum materials required for O&M, only chlorine	Fuel, treatment chemicals, spare parts may not always be available

Decision: Where the present worth of Alternative B is less than 10 to 20% lower than A, the non-quantifiable factors should enter the decision. These show advantages for the gravity system in Alternative A, hence it should be selected.

15.2 Affordability and Willingness to Pay

For each proposed system an analysis should be carried out to evaluate whether the community to be served (1) can afford the project, and (2) is willing to pay for the proposed level of service. The cost to be borne by the community depends on the conditions of project financing (such as interest rates and the level of capital grants and subsidies); and the level of service provided. When the financial conditions are known, the only open variables relate to the level of service.

Ability and Willingness to Pay and Level of Service

It is important to distinguish between affordability or ability to pay and willingness to pay:

Ability to pay depends particularly on the economic conditions of the potential users. The ability to pay has been suggested to be about 3 to 5% of family income, although this may vary considerably depending upon the nature of the economy; a subsistence economy will afford less for water.

Willingness to pay, however, is most likely influenced by the actual and perceived utility and benefits of an improved water supply. Factors likely to influence willingness to pay include: (i) household income; (ii) potential of additional income or savings due to the improved water supply; (iii) the level and value of time saved; as well as (iv) the perceived convenience, reliability and quality of the improved service versus the old service. The last two factors tend to be strongly influenced by the level of service provided.

Experience in Thailand (Dworkin, 1982) and other countries (Golladay, 1983) suggests that the least costly solution, providing a low level of service, may provide too little perceived benefits to the users to get them to be willing to pay for construction or maintenance of an improved water supply system. This applies especially where existing water sources are conveniently located, even though they may not provide safe water (such as shallow wells close to houses). People may have too limited understanding of the benefits of safe water to be willing to pay for an improvement of water quality alone. However, convenience, reliability, and quality afforded by a higher level of service, and public education regarding the potential benefits, are likely to increase the willingness to support a new water supply system. Where householders have been purchasing water from distributing vendors, the price they pay per month is a useful indicator of willingness to pay. Piped water services have always been found to be less costly to the consumer than vended water on a per cubic meter basis, and even on a monthly basis, where the per capita consumption of piped water is much higher.

The evaluation of costs of various levels of service and community information and involvement are key components in the analysis of willingness to pay for and support a new or improved water supply system. Cost functions (section 15.4) provide a simple tool to estimate the costs of various elements of service. Based on these estimates, users can be informed about the approximate costs they would have to bear given local financing conditions. The users should be informed about the benefits of various service levels through a specially designed information campaign or pilot projects which may demonstrate actual services to people in a project area.

Factors to Be Considered in the Analysis

The following factors tend to influence capital and operating costs, and should be considered in an analysis of affordability and willingness to pay. The numbers in brackets after each paragraph refer to the sections of the manual that discuss this factor further.

- Level of service: Supply through standposts (level I), yard connections (II) or house connections (III), or a mix of these service levels, should be based on affordability and willingness to pay by community members [4.2].
- Use of flow restrictors: This measure for yard and house connections allows reduction in peak flow, reducing cost of distribution, but requires private storage facilities; experience has shown that flow restrictors are viewed as an impediment by users, and are often removed or altered [6.6].
- Network layout: Branched or looped network. The looped network requires more pipe length but increases the reliability of the supply [4.2 and 12].
- Metering: Meters encourage economy in use of water, especially when accompanied by a rational tariff system [6.5 and 15.4].
- Provision of fire flow capacity: Is only appropriate for larger communities with high property values [6.4].
- Minimum residual pressure: Increased minimal residual pressure increases reliability of supply during high demand periods [11.2].

15.3 Financial Planning

Financial planning should ensure that sufficient funds are available at all stages of the project by considering the costs and revenues of a project. Important considerations include financing, financial management, and the setting of tariff structure.

The costs the community has to meet include: (i) the full (or portion of the) capital costs which the community may have to provide at the start of the project as a down payment (usually about 10 to 30% of the total capital costs); and (ii) amortization of the remaining capital cost, debt service, and operation and maintenance.

Financial costs may be reduced by grants from internal or external sources which cover part of the capital costs, or loans with interest rates below the market rates. In cases where full cost recovery is not feasible, direct or indirect subsidies of even the operation and maintenance costs may be required to keep these costs at an affordable level. Indirect subsidies may consist of logistic and maintenance support by regional institutions below actual costs. Communities that promise full cost recovery may enjoy a higher priority.

> **Note:** The local manual should indicate: (1) the downpayment required from the community in percent of capital costs, (2) the level of possible grants and the conditions to obtain such grants, and (3) the level of interest rates. Criteria for priorities, if they exist, should be stated.

Cost calculations should be presented in actual monthly costs per household and in cost per m^3 water consumed. For large projects, cost calculations may be considerably simplified by the use of microcomputers and so-called spreadsheet programs. (See Annex 3)

Sources of Funds

Sources of capital funds may be local, national, or international; they may further be classified as public and/or private.

Local Financing

Local financing may be accomplished through both financial contribution and direct contributions of labor, materials and land.

Financial contributions may be obtained through: (a) the sale of bonds, which may be repayed from local taxes and/or income generated by the project; (b) down payments by customers for water connections (amount depending on the level of service and size of connection); (c) local taxes on property or through any other appropriate local tax system.

Contributions of land, labor and sometimes material may be particularly feasible in small communities with low income generation.

Where subsidies or loans from national or international sources are available, the willingness to contribute appropriate local resources may be an important factor in establishing priority with the donor agency.

National Financing

Small communities with highly limited resources may depend on the provision of subsidies and/or loans to cover the planning and construction costs of a new or improved system. Such grants and loans may be provided by national development banks which extend credit to local or provincial agencies (see chapter 18).

The portion of credit or grant provided and conditions for such support (interest rate and pay-back period) depend on the economic resources of a community and its willingness to pay and/or contribute to the capital costs.

The development bank may obtain its funds from international agencies or through bilateral loan agreements at lower than market interest rates. Returns from loans provided to local communities may help to maintain or even increase the resources of the development bank. A revolving fund may be established for the sector.

International Sources of Funds

Annex 1 lists a number of international agencies which commonly provide funding and/or technical and institutional assistance for water supply projects. Funds may also be obtained through direct bilateral loan agreements with a many industrialized countries or their development agencies. However, a considerable portion of funds from these countries are provided through or in connection with international agencies listed in Annex 1.

Aid policies usually vary from country to country and agency to agency, as well as over time, and are therefore not presented in any detail. Generally the availability of loans and other assistance is influenced by:

i) the presence of institutions capable of administrating and managing the proposed projects;

ii) the availability of local funds and willingness to pay the costs of local labor and materials, as well as the operation and maintenance costs;

iii) ability of the borrower to repay the loans and sound administrative and financial practices to ensure such repayments.

Project Financing

Even though many international organizations support water supply projects in developing countries with loans and grants, foreign assistance can only act as a catalyst in providing improved water supply. Most of the required funds for water supply will have to be generated internally, and careful financial planning is essential. This planning should include:

(i) budgets at the national, regional, and project level which consider all required investments in planning, construction and operation and maintenance of planned facilities, including costs of supportive programs such as staff training and institutional development.

(ii) a policy on financing the capital and O&M costs and supportive programs of all planned and existing projects.

A realistic financing policy has to rely to a large extent on local resources. It should be based on: (i) an implementation schedule which considers the capacity of the existing institutions and the constraints of the national budget, (ii) funding rules and criteria for various categories of communities, depending on their size and economic condition, and (iii) a dete[Bined policy to recover locally all costs, including capital as well as O&M, to the greatest possible extent in order to free national resources for the implementation of new systems.

Funding rules should indicate the criteria under which the government will provide repayable loans at low interest rates, or grants for systems which provide a specified minimal level of service. Higher interest rates (near or at the market level) should be requested for providing higher levels of service. Funding rules may also include a provision to grant short term loans for the costs of yard or house connections to users, as this measure is likely to increase the affordability and willingness to pay.

In some low income areas, a major portion of the capital costs may have to be granted. However, whenever possible it should be ensured that the users are able and willing to support at the very least the operation and maintenance of the system. Otherwise, resources planned to provide new people with adequate water supply may have to be spent on subsidies to keep existing systems in operation. Often, assistance may be provided through contributions of labor and material by the local communities.

> **Note:** The local manual should specify the funding rules and the criteria for their application.

Financial Planning and Management at Community Level

Sound financial planning and management at the community level is the basis for recovering the financial resources invested and the operation and maintenance costs. It should include: (i) an analysis of ability and willingness to pay for the planned service, (ii) the implementation of an adequate and fair tariff system, (iii) the development of an adequate revenue collection system, and (iv) the preparation of an income statement. The last is an important item to be included in an O&M manual.

Water Tariffs

The tariff structure should be approximated in the planning stage so it can be used in connection with analysis of the willingness to pay, and be part of the community communication process which tries to assess the feasible level of service. Tariffs, ideally, should be: (i) designed to generate sufficient revenue to meet all costs; (ii) reasonable; (iii) simple to understand; (iv) easily administered; and (v) not exceed the ability or willingness to pay of users.

Two approaches for charging water service, both being required to meet the total costs, are widely used: (a) without meters, a flat rate; and (b) with meters, a rate that is some function of the use. Each approach has many variations. Without meters, a flat rate is determined by dividing the total income needed equally among the users; where households have more taps, or more people, or special needs, such as watering, they may pay at a higher rate. With meters, a common rate structure includes a service charge which covers a fixed use per month, say 5 m^3. All use in excess is charged at a higher rate per cubic meter, with possibly increasing rates per m^3 for each increment.

Table 15-4 illustrates two metered rate structures: A is a uniform rate per cubic meter for each household, while B allows a lower base rate and a higher rate for larger users.

The advantage of meters is that they impute a value to the water. Consumers pay for the volume of water used, and are thereby discouraged from wasting water. Without a meter, the water appears to have little value and consumers have no incentive to conserve or prevent waste. However, meters cost money to purchase, maintain, and read. If water is plentiful and flows by gravity and requires little treatment, meters may not be worth their cost.

> **Note:** The responsible planning agency should decide if it will make it policy of the national rural water supply program to require that connections be metered.

15.4 Cost Estimating

Cost estimates are necessary in order to:

(i) compare alternatives (such as different water sources, or the provision of several separate small systems versus a larger regional system) and ensure that the proposed approach is the least costly way of providing the desired level of service;

(ii) provide the community with information on costs so they can select the appropriate level of service;

(iii) evaluate the economic consequences of various planning periods and project staging;

(iv) develop a financial schedule for construction and operation and maintenance phases; and finally

(v) arrange for the necessary financing.

Cost estimates include both capital (or initial) costs, and operation and maintenance costs. Capital costs are those incurred in providing the water system. Operational costs are those required, year after year, to operate and maintain the system.

Capital Costs

Capital costs include the following project components:

Land: Its cost is generally determined by market values. Low-cost land that does not interfere with other uses but meets water system requirements is

Table 15-4 Illustrative Water Tariff Structures

	Tariff Structure Uniform Rate (A)	Tariff Structure Rising Rate (B)
Revenue required by water utility to meet monthly costs ($/month)	1,000	1,000
Number of families:		
Basic consuming families	100	100
Higher consuming families	400	400
Total	500	500
Family consumption (m^3/month)		
Basic consuming family	5	5
Higher consuming family and other consumers	16	16
Total consumption (m^3/month) /a	6,900	6,900
Average tariff ($/$m^3$) /b	0.145	0.145
Monthly payment by basic consuming family	0.73/c	0.50/f
Monthly payment by higher consuming family	2.32	2.37/j
Tariff for first 5 m^3/month ($/$m^3$)	0.145	0.100
Tariff for additional m^3/month ($/$m^3$)	0.145	0.170/c
Total revenue from basic consuming family ($/month)	73/d	50/g
Total revenue from higher consuming family ($/month)	927/e	950/h
Total Revenue ($/month)	1,000	1,000

/a Calculation of total consumption:
Consumption by basic consumers = 100 families x 5 m^3/month = 500
Consumption by higher consumers = 400 families x 16 m^3/month = 6,400
Total consumption = 500 + 6,400 = 6,900 m^3/month.

/b Calculation of average tariff.
Revenue required : total consumption
1,000 : 6,900 = 0.145 $/$m^3$

/c 5 x 0.145 = 0.73

/d 0.73 x 100 = 73

/e 1000 - 73 = 927

/f 5 x 0.10 = 0.50

/g 100 x 0.50 = 50

/h 1000 - 50 = 950

/i Revenue earned from first 5 m^3/mo: 400 x 5 x 0.10 = 200
Volume above 5 m^3/mo = 11 x 400 = 4400
Tariff above 5 m^3/mo = (750/4400) = 0.170

/j 5 x 0.1 + 11 x 0.17 = 2.37

preferred. Land for transmission lines can be obtained at low cost through right-of-way easements.

Planning and Engineering: The costs of planning and engineering, which includes design and supervision of construction, are commonly estimated at about 10% of the total project cost. This percentage is influenced by local conditions and the size of the system, with higher percentages for smaller projects. This amount should be added to the project cost to ensure that planning and design are adequately funded. Supervision of construction may be handled by the owner, the design organization, or a construction supervisor employed by the owner.

Materials and equipment: Estimates of the costs of materials and equipment for construction are based upon experienced costs in the vicinity. If these are not available, the selling price at the factory plus the costs of transportation from the factory to the job site may be estimated. Materials and equipment may have an official price and a higher free-market price. A judgement must be made as to which shall be used. Equipment costs may include cost of installation and training of operators.

Labor: Construction costs include all wages and other related costs such as social support fees and provided clothing and protective gear. The cost of the use of construction equipment, including fuel and maintenance, must be included. Some of these costs may be built into the unit prices for construction.

Base Cost: The base cost of a project or facility is the sum of all above costs, prior to the addition of engineering design and contingencies. These might be used to develop cost functions. Typical cost functions and their development are discussed later in this chapter.

> **Note:** The local manual should indicate common local costs for required materials, labor, equipment and transportation for construction as shown in Annex 5. If costs vary considerably within the project area, separate cost tables may have to be developed.

Physical Contingencies: About 10 percent of the base cost should be added to include unforeseen or overlooked costs, such as unanticipated rock excavation or site dewatering, and uncertainties in unit price estimates. Examples of project element estimates are shown in Annex 5.

Price Contingency includes inflation of costs during construction. The calculation of the price contingency is demonstrated in the following example, assuming 100% borrowing and uniform drawdown during construction:

Total Estimated Construction Cost in mid-1986, at current market prices	$200,000
Period of Construction: 3 years with 30% per year to be spent in 1987 and 1988, and 40% in 1989.	
Rate of Inflation: say 3%	
Cost at current price in 1987: 1.03 x 60,000 (30% of 200,000)	61,800
Cost at current price in 1988: 1.03 x 1.03 x 60,000	63,654
Cost at current price in 1989: 1.03 x 1.03 x 1.03 x 80,000	87,418
Total cost at current prices	$212,872

Price Contingency: $212,872 - 200,000 = $12,872

The capital costs should be estimated in consultation with agencies experienced in local construction practice which will have in their files the costs of materials, transport, labor and fuel on previous projects in the region.

Interest payment during construction phase: Interest payments for loans during the construction phase should be included in the capital costs, as illustrated below for the example above with the same assumptions:

Year	Construction Cost	Interest (10%) for Loan	Total Capital Cost
1986	$ 61,900	$ 61,900 X 0.10 = $ 6,180	
1987	63,654	$125,454 X 0.10 = $12,545	
1988	87,418	$212,872 X 0.10 = $21,287	
TOTAL	$212,872	$40,012	$252,884

Interest during construction represents almost a 20% increase in capital cost.

Costs of Supportive Project Components

Such costs include expenditures for: (i) training programs, (ii) regional supportive institutions and facilities which provide technical, logistic and administrative support to small local systems and utilities, (iii) promotion of community participation and health education programs, (iv) sanitation programs, or (v) pilot projects and evaluation studies.

The costs of these programs should be estimated with the support of specialists in these fields or based on cost data of earlier, similar programs. They may be financed by special project budgets and be paid directly by the planning agency or government; or they may be proportioned among individual systems as support or overhead costs. Depending on how they are financed, they can be part of the capital costs for one-time expenditures or part of O&M for continuing expenditures.

Expenditure Schedules

Capital costs are incurred over time as the construction progresses. The costs of planning and design occur first, and are followed by the cost of purchasing materials and equipment, and construction costs. For large projects the capital costs may be spread out over several years. The financing of the project during construction, when user charges cannot be collected, are part of the capital cost. An expenditure schedule should be developed to determine how the costs would be distributed year by year so a budget and financing plan can be developed. The example is continued below:

Expenditure Schedule

	1986	1987	1988	Total
Capital Cost	67,980	76,199	108,705	252,886
% Expended	27%	30%	43%	100%

Operation and Maintenance Costs

Operation and maintenance costs comprise all expenditures which are required to keep a system in operation and good condition after it is placed on line. They include expenses for personnel, chemicals, electricity, fuels, materials, maintenance, spare parts, office supplies and rents for buildings, vehicles and other equipment. Costs for modest system expansion may also be included. Table 15-5 illustrates O&M costs.

Note: The local manual should include a list of local costs of all manpower, chemical, fuels, electricity and materials required for operation and maintenance.

Table 15-5 Example of Unit Costs for Operation and Maintenance

Item	Unit	Quantity	Unit Cost	Total
1. Labor:				
Operators	Person-years	2	$2,400	$4,800
Administrators	Person-years	1	3,000	3,000
Maintenance workers	Person-years	1	2,400	2,400
2. Chemicals				
Chlorine	Kilos	120	2	240
Lime	"	2,400	0.2	480
3. Electricity	KW-hr	2,000	0.08	160
4. Fuel	Liters	1,000	0.5	500
5. Maintenance materials	Lump sum			150
6. Supplies (for office)	Lump sum			30
7. Rent (if a building is rented)				1,240
Total operation and maintenance cost				$13,000
Total water produced				42,000 m^3
Unit cost for operation and maintenance: $13,000/42,000 m^3 = $0.31/$m^3$				

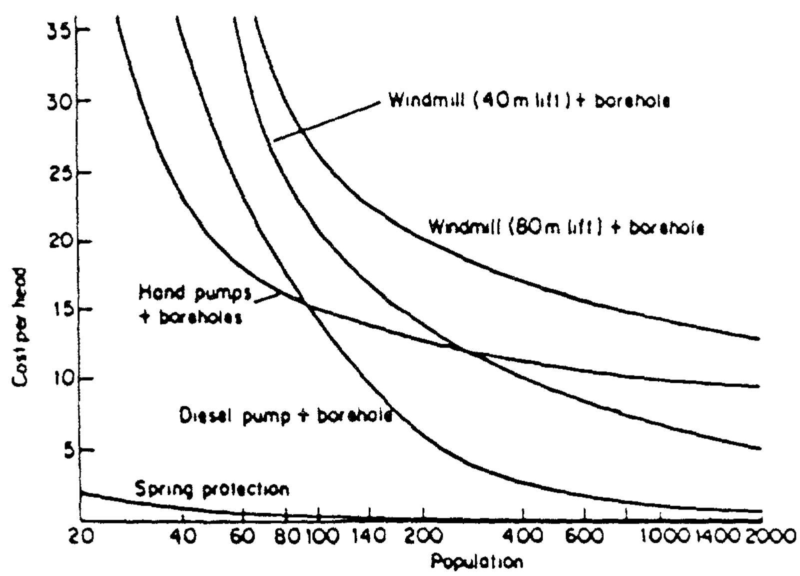
Cost Information for Preliminary Estimates

Unit costs obtained from past experience provide a useful tool for making preliminary cost estimates which can be used for comparing project alternatives. They may be expressed as: (a) capital cost per unit capacity, which is determined by dividing the total capital cost by system capacity, expressed in terms of cost per cubic meter per day capacity, per household, or per capita; or (b) total annual water production costs, including capital and O&M per cubic meter of water delivered, per household, or per capita, which are calculated by dividing total annual cost by total volume of water delivered in the year by connected households or by population.

Such unit costs vary widely with the size of the project, availability and distance of water source, population density in the supply area, etc. Their usefulness may be improved to some degree by estimating unit costs for systems with various water sources and various community sizes. Such cost data may be plotted against the system size (Figure 15-1) and used to get a rough idea of which type of facility or system may be the least cost solution in a community of a given size, or to establish the minimum community size where a piped system is likely to be feasible if compared to individual wells with handpumps. Table 15-5 shows an example of unit costs for operation and maintenance, and Annex 6 illustrates a wide range of unit costs.

Unit costs tend to decrease with increasing capacity (Figure 15-1). Regional facilities may therefore cost less per cubic meter of water produced or per household served. Elements of the system, such as pipelines also tend to show economies of scale. The determination of economy of scale factors in establishing cost functions is discussed in the following section. Cost data should always be dated so future users of the data can update them by accounting for inflation.

Figure 15-1 Cost Graph for Comparison of Various Types of Water Supply. Note that population is plotted on a logarithmic scale.



Source: Cairncross (1980)

Cost Functions

The variation of costs due to economies of scale and other factors may be represented by relatively simple mathematical functions or equations. Such functions present local planners with an efficient planning tool which enables them to carry out evaluations more easily.

Cost functions are derived from data on costs obtained from similar projects in the vicinity or, where these are not available, by estimating costs based on materials, transportation, and installation costs. These data are plotted on graphs showing the size or capacity of the item on the abscissa and the cost on the ordinate. The points are connected by a smooth curve. For various related items, a family of curves can be drawn (see Annex 6). The functions may be used from these graphs, but more often, especially when they are to be used in a computer, they are converted to equations as shown in Table A6-1.

Where the data plot approximately as a straight line (Figure 15-2,a), an equation of the following form is easily obtained:

$$C = c + bQ$$

where
- C = total cost,
- Q = capacity or size of the facility,
- c = fixed cost, a constant; and
- b = unit cost factor.

A more common function is the so-called power function (Figure 15-2b):

$$C = bQ^{a}$$

where a = economy of scale factor.

When $a=1$, this is the same as the previous equation, and would plot as a straight line. More often a is not 1. Very commonly, the cost increases at a slower rate than the capacity increases, resulting in the so-called "economy of scale". In such cases a is less than 1; the smaller the value of a, the greater the economy of scale. An example is a storage tank where the cost increases as the size of the tank increases, but the cost per cubic meter of storage is smaller with a larger tank.

Developing this power function is relatively simple. The data tend to plot as a straight line if log-log paper is used, or if logarithms are taken:

$$\ln C = \ln b + a \ln Q$$

Accordingly, the data are plotted as logarithms, or more conveniently on log-log paper, and fitted to a straight line. The value of b is the C intercept where $Q=1$, the cost of a unit, and the value of a is the slope of the line (Figure 15-2c). The values of a and b are taken from the plot, and an equation for the power function is obtained. If a computer is available, a and b can be determined by regression analysis. Annex 6 shows such functions both in graphical and mathematical forms (Figures A6-2 and A6-3.

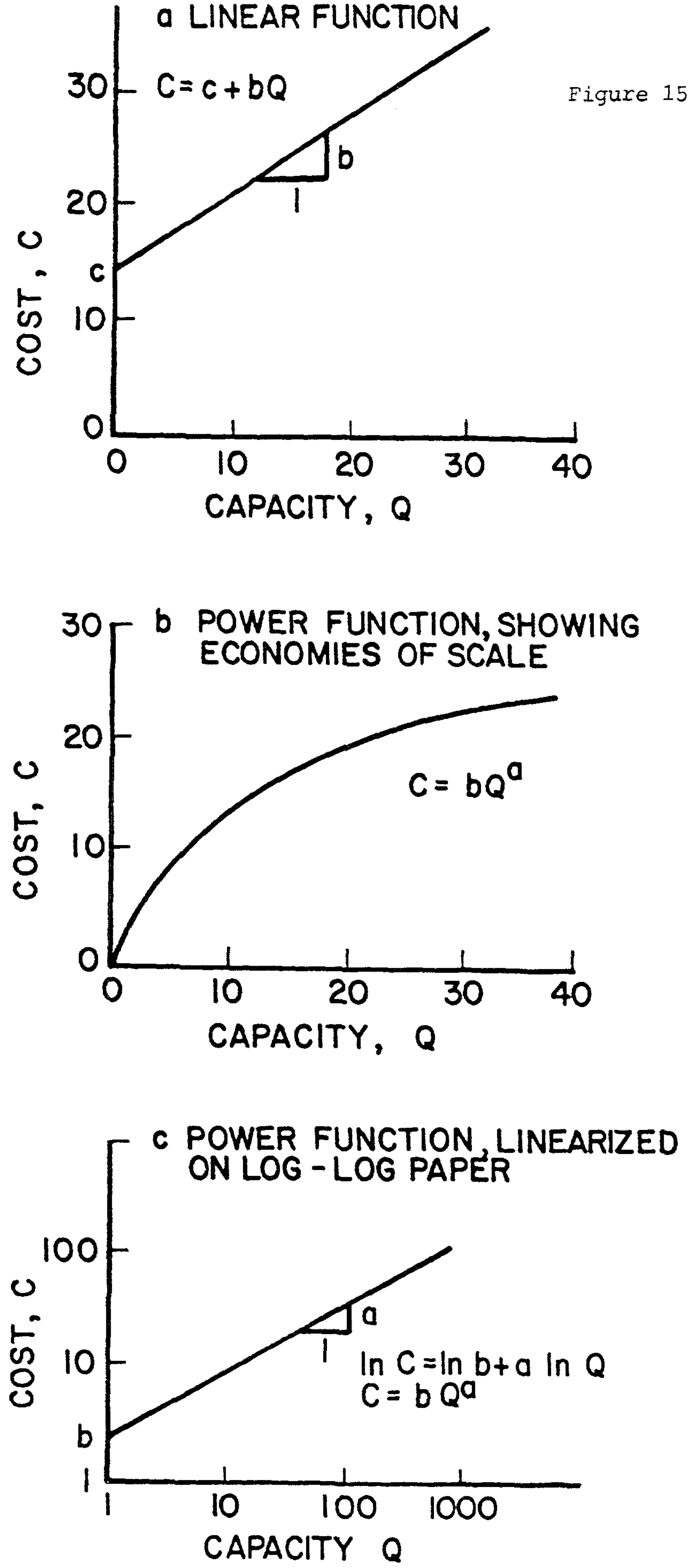


Figure 15-2 Typical Cost Functions

The exponent a, the economy of scale, tends to be about the same for any particular item, whereas the unit cost b is very much dependent on the local circumstances. Accordingly, where local data are limited, a useful approach is to estimate a from similar facilities elsewhere, such as are listed in the Annex, with the unit cost b being determined from the equation

$$b = C/Q^a$$

where C is the cost of the local facility, Q its capacity, and a is selected from cost functions developed elsewhere. This is illustrated in Table A6-1, where the economy of scale factors for pipelines, water treatment plants, and storage tanks are very much the same for each type of facility but the unit costs vary substantially.

Annex A6, Table A6-1, lists many cost functions which are indicative of those that need to be developed locally. They are not suitable for use as shown because they were derived years ago and the costs would need to be updated. More important, they were derived for other places where materials and labor costs are likely to be different. However, the economy of scale exponents may be useful.

Economies of scale for treatment facilities vary, depending on the type of plant and local conditions, between about 0.6 and 0.9 (Ringskog, 1979; Lauria, 1982; Schulz 1984). Cost equations to be used in individual projects should therefore be based on local cost data and established for technically appropriate types of facilities.

The development of cost functions for small facilities needs special consideration. Linear cost functions should be used because the cost of the first unit (b) is increasingly important with decreasing size.

Cost functions may be used for most of the economic evaluations during the planning process including: (i) initial cost estimates for project identification and pre-feasibility studies; (ii) screening alternative designs for the least cost solution and evaluation of the best combination of system components; and (iii) evaluation of the costs of providing various levels of service.

15.5 Examples of Financial Considerations in Planning

The following examples illustrate a few of the many applications of financial considerations to water supply projects:

- Piped system versus individual handpumps: The costs of providing community handpumps are usually relatively constant in a given region. The costs of piped systems with public taps, which could provide a similar level of service, are likely to vary considerably with community size and other factors. With the help of local cost functions, reasonably accurate estimates for piped systems can be made to determine whether a piped standpost system is cheaper than the installation of hand pumps in a community.
- Individual community systems versus a regional system: Similarly, a regionalized system can be compared with several separate systems. This is illustrated in Table 15-6, where the regional system is estimated to be about 20% less costly than three separate systems.
- Selection of water sources: If cost functions for wells, intakes, transmission pipelines, pumps and treatment facilities, and their recurrent

Table 15-6 Cost Comparison of Individual Community Systems Versus a Regional Supply System

Items		Individual Water Supply System A	B	C	Regional Supply System
Pipe network (m):	D 150 mm				330
	D 100	100			600
	D 75	540	340	100	1000
	D 50	670	840	970	2410
	D 40	800	600	600	2000
Storage tank (volume, m^3) 20 m high		30	30	30	50
Clear well (volume, m^3)		40	30	30	80
Water purification structures (capacity, m^3/hr)		20	15	15	50
Pumps (number)		4	4	4	4
Area of buildings (m^2)		60	60	60	140
Fence		100	100	100	110
Chemical equipment (unit)		1	1	1	1
Land (m^2)		600	600	600	700

Economic Analysis (U.S. $)

Item	Individual Water Supply System A	B	C	TOTAL	Regional Water Supply System
Pipe cost	10,500	10,000	9,500	30,000	35,000
Construction cost of WTP	8,000	8,000	8,000	24,000	14,000
Total capital cost	18,500	18,000	17,500	54,000	49,000
Annual O&M cost	1,400	1,000	1,000	3,400	2,400
Present worth factor (i=10%, 30 yrs)				9.43	9.43
Present worth, O&M cost				32,000	22,600
Total present worth				86,000	71,600

costs are available, the present value or the annual costs for various alternatives can be evaluated and the least cost combination selected.

- Extensions of a piped network: In communities with dispersed populations it may be necessary to find the feasible limits for extension of the network by evaluating where the increase in network costs to serve an outlying section is higher than providing these outlying residents with handpumps or another appropriate individual supply (or in economic terms: where the marginal costs of a piped system are greater than the costs of individual systems).

- Evaluation of storage tank location and size: In areas with sufficient topographical rise in the neighborhood, the choice between a ground storage tank including the necessary extension of the transmission pipe and an elevated tank near the center of the community can be evaluated by using appropriate cost functions.

- Optimization of the design period: Other factors being equal, the economically optimal design period is determined by the economies of scale and the prevailing discount or interest rates. If the economy of scale factor of a particular facility has been determined through the development of its cost function from similar facilities in the region, or from generalized formulas, the following formula can be used to determine approximately its most economic design period (DP):

$$DP = [2.6\ (1-a)^{1.12}]\ /\ (i)$$

where a is the economy of scale factor and i the interest or discount rate. This formula highlights the fact that the optimal design period is affected by economy of scale factors, with larger economies of scale (lower a values) calling for longer design periods. Table 15-7 indicates optimal design periods for some typical economy of scale factors for expansion of water supply facilities, and various discount rates.

Table 15-7 Optimal Design Periods (Years)

Economy of Scale Factor (a)	Discount Rate % 8	10	12	15
0.3	22	17	15	12
0.5	15	12	10	8
0.7	8	7	6	5
0.8	5	4	3	3

The smaller the economy of scale factor and the smaller the discount rate, the longer the optimal design period.

- Income and Expense Statements: The methods of calculating costs can be used to develop income and expense statements, as illustrated in Table 15-8. These can help establish needed tariff structures and plan for financing for the duration of the project life. Of course, based on operating experience, such statements need to be modified regularly.

Table 15-8 Income and Expense Statement

	Months (1)	(2)--(11)	(12)	Total for Year	Previous Year
Income					
Population					
Population served					
By house connections					
By public hydrant					
Number of connections					
Residential					
Public hydrant					
Industrial/commercial					
Volume of water produced (m^3)					
Volume of water sold (m^3)					
Percent water unaccounted					
Average tariff $/$m^3$)					
Water sales revenue ($)					
Other revenue ($)					
Total revenue ($)					
Expenses					
Labor					
Chemicals					
Electricity					
Maintenance materials					
Other					
Subtotal (O&M costs)					
Amortization					
Total recurrent expenses					
Depreciation					
Total cost of water					

Income statements usually include data for several periods of time, for example; for 12 months, the full year, and a previous year so that comparisons may be made between periods.

15.6 Definitions

Capital costs are costs of the project from its beginning until placed in operation. Included are: (i) the purchase of land and rights-of-way; (ii) payments for planning, engineering materials, equipment and construction; and (iii) interest charges during the construction.

Principal is the amount borrowed which has to be repaid.

Amortization is the monthly or annual repayment of the loan principal. It is normally expressed in a series of payments over the loan period.

Interest is the cost of borrowing money. It is expressed as a rate (i) of the principal in per cent per year.

Fixed charges are the annual payments to repay capital costs including both amortization and interest, plus taxes.

Annualized capital costs represent a series of uniform annual payments (UAP) required to fully cover the capital costs or principal and the interest over the lifetime of the project (n years) assuming an interest rate (i). UAP's are calculated by multiplying the principal by the capital recovery factor (CRF) which can be expressed as:

$$CRF = [i(1+n)^n]/[(1+i)^n-1].$$

Operation and maintenance costs include all expenditures for operation of the facilities, their maintenance, the replacement of equipment in the normal course of operation, and normal extensions.

Annual costs include the sum of operation and maintenance costs and the annualized capital costs.

Discounting describes the practice of reducing future costs or benefits to an equivalent present worth (PW). The present worth of a single payment (S) is calculated by multiplying (S) by the present worth factor (PWF): $PWF = [1/(1+i)^n]$. The present worth of a series of uniform payments (R) is calculated by multiplying the (R) by the series present worth factor: $(SPWF) = [(1+i)^n-1]/[i(1+i)^n]$.

Unit costs are capital or annual costs expressed per unit of capacity or size, or per capita or per household, etc.

Chapter 16

Logistic Support

Logistic support includes the timely:

(i) assessment, scheduling, procurement (or production), storage and distribution of all required materials and equipment;

(ii) assessment, scheduling and preparation of all required supportive facilities such as offices and workshops;

(iii) assessment, scheduling, recruitment, training and organization and management of the required personnel for all project stages; as well as

(iv) standardization and quality control of materials, equipment, design and construction.

Logistic planning is important because the resources of skilled people and required materials and equipment are usually limited, particularly in rural areas. Private sector or public organizations that provide logistic support in industrialized countries are not yet developed.

This chapter focuses on estimation of the required materials, equipment and facilities; scheduling; standardization, quality control, and the development of a design and construction manual. Personnel and institutional development are discussed in Chapters 17 and 18, respectively.

16.1 Required Materials, Equipment, and Supporting Facilities

The specific needs for materials and equipment vary widely from project to project, so the presentation is necessarily general. Some of the material and equipment is discussed in the appropriate technical section of the manual.

Planning and Design

The materials and equipment required for water supply projects include:

- Surveying equipment (such as measuring tapes, levels and theodolites) to develop or improve topographic and location maps and topographic profiles;
- Meteorological, hydrological and hydraulic equipment such as rain gages, current meters, flow measurement weirs, water level recorders, pitot tubes and water meters;
- Equipment for groundwater investigations, such as electrical resistivity and seismic refraction instruments, drilling equipment, etc. The appropriateness of such equipment depends on local conditions as detailed in Chapters 7 and 8;
- Office, laboratory, workshop and storage facilities including temporary field offices for investigations;
- Office equipment, including calculators, typewriters, drawing tables and equipment, desks, file holders, and bookshelves;
- Water quality testing equipment for bacteriological and chemical analysis, if not available elsewhere in the project area, including glassware, filters, sample vessels, incubators, and reagents (World Health Organization, 1983, Guidelines for Drinking Water Quality, Volume III);
- Leakage measurement and detection equipment if rehabilitation of existing systems is included in the project;
- Vehicles for transporting personnel and equipment if not more economically rented.

Some of the material, if only required during planning, design, and construction stages, may be rented.

Construction

The construction of community water supply systems usually requires the following materials, equipment and facilities:

- Earth moving equipment;
- Pipes and appurtenances such as valves, hydrants, and water meters, including equipment for pressure tests of the pipelines such as pumps, endcaps, and pressure gauges;
- Pumps, treatment facilities, tanks and pumping stations;
- Well drilling equipment and wellcasings;
- Cement, reinforcing steel, sand, gravel and shuttering wood for preparing concrete structures; and clay, bricks or concrete blocks for buildings;
- Surveying equipment to guide pipelaying and construction;
- Concrete mixing, compaction and testing equipment which are particularly important if concrete storage tanks are which require high quality water-tight concrete are planned;
- Transportation vehicles for materials, equipment and personnel;
- Storage facilities for pipe materials, appurtenances, pumps and other equipment, cement, and reinforcing steel;
- Office facilities and equipment for site offices; and
- Fuel and spare-parts for construction equipment and vehicles; and
- Water.

Operation and Maintenance

The material, equipment and facilities required for operation and maintenance include offices, workshops, laboratories, vehicles, office and laboratory equipment, tools, leakage detection equipment, etc. (Chapter 14).

Estimating Required and Available Resources

The level of precision and the methods of estimating quantities of construction material and equipment depend on the stage of planning.

For project identification reports and pre-feasibility studies, only rough estimates are required to develop a first implementation schedule as well as to assess the required logistic support. Such estimates are usually based on data from existing systems with similar conditions or, if no such systems exist, on preliminary designs of typical systems of varying size.

Based on such data, tables can be developed which indicate how much materials and personnel are required to build a distribution network for 100, 500, 1000, 5000, or 10,000 households with a specified level of service or specified mix of service levels (see Table 16-1). Similar information should be developed which indicates the resources required to develop various types of water sources, and to build the required transmission lines and pumping, storage and treatment facilities. Such estimates only provide approximate numbers because they cannot consider local conditions.

Another, more sophisticated approach is based on regression models similar to those discussed for cost functions in Chapter 15. Table 16-2 presents such a model developed in Nepal for the resource estimation for service reservoirs. Similar models may be developed for networks based on average diameters and for other facilities.

For feasibility studies of individual subprojects, a preliminary design of the network and the required facilities is usually carried out. This allows a more detailed estimate which considers the special local conditions of each individual system. These data can be used to develop a construction schedule for the project.

An assessment of available resources should consider the availability of personnel at different skill levels in the project area and costs and resources required to develop additional personnel; and the capacity of local manufacturers to produce required materials and equipment, and the cost and time required to increase such capacities, if necessary.

These assessments should consider the demand by other private and public projects and include contingencies which account for potential production and distribution problems.

Table 16-1 Estimate of Materials and Personnel for Piped Standpost Systems

a) Distribution Network		Households per System (Length in m)			
		500	1000	5000	10000
Pipes Diam. (mm)	25				
	50				
	100				
	150				
	200				
	250				
	300				
	400				
	500				
Personnel (person-days):					
Skilled workers					
Unskilled workers					
b) Transmission Mains*					
Average Diameter					
Personnel (person-days/1000 m)					
Skilled workers					
Unskilled workers					

*Fittings and valves may be estimated by an average number per 1000 meter of pipeline: 4 bends, 1 valve and 2 air release valves for transmission lines; or 4 tees and 4 valves per 1000 meters for distribution networks.

Table 16-2 Regression Models for Determining Service Reservoir Material Requirements

Res. Size m^3	Skilled man-day	Unskilled man-day	Cement bags	Sand m^3	Bricks nos.	Gravel m^3
1	18	40	14	1.8	1,200	.5
2.5	25	75	21	2.9	2,750	1.8
4	30	95	28	3.9	3,700	2.3
8	46	174	48	7.0	5,000	5.5
12	56	213	58	8.3	5,800	6.6
16	70	264	71	10.2	7,000	8.3
20	73	290	80	11.4	8,000	8.9
30	102	397	105	15.3	10,000	12.3
40	108	482	122	18.2	12,275	18.8
50	121	560	140	21.0	14,000	23.1
60	133	634	157	23.6	15,500	27.3
80	154	770	187	28.3	18,400	35.6

GENERAL MODEL

$\ln y = \ln b + a \ln V \qquad y = aV^b$

y = dependent variable, units as above

V = capacity of reservoir, m^3

a, b = constants developed from regression models.

Skilled labor	=	$16\ V^{0.51}$
Unskilled labor	=	$40\ V^{0.67}$
Cement	=	$13\ V^{0.6}$
Sand	=	$1.7\ V^{0.64}$
Bricks	=	$1400\ V^{0.58}$
Gravel	=	$0.64\ V^{0.92}$

Source: Marinshaw (1983)

16.2 Scheduling

The major objective of logistic planning is to assure the provision of the required physical and human resources for each planning stage. Proper logistic planning reduces the time required to complete the project and makes best use of available resources required during each stage. A task which requires 50 skilled people and 10 trucks to be completed in 1 week may require only 10 skilled workers and 2 trucks if carried out over a period of 5 weeks.

Logistic planning therefore has to be based on time schedules which consider the available resources and their economical use.

In industrialized countries with relatively large reserves of physical and skilled human resources, the time-frame of a project or task is usually set by technical and economic constraints. In most developing countries the constraints are quite different. Skilled personnel (such as engineers and technicians) are usually limited in numbers. In addition, the supply of physical resources such as pipe materials, fittings or cement is often limited by local production capacity, production difficulties, limited transportation capacity, or by limited capacity of local institutions, such as customs offices.

Implementation Schedules

Implementation schedules are prepared to permit various project stages to be undertaken to make the best use of the available resources and to avoid delays in completion of the work. As a first step, all activities of each project stage and their duration and sequence are determined (see chapter 3), and the required and available resources for these project stages and activities are estimated.

The implementation schedule should split the project into a number of basic activities including: (i) all major stages of all proposed sub-projects (feasibility study, detail design, procurement and supply of materials and equipment, construction and system start-up); (ii) all relevant supportive project components, such as training and institutional development, as well as (iii) all relevant infrastructure development, such as electricity supply and road access. In a second step, a preliminary schedule is developed for the time periods where the resources are likely to be most critical.

A simple way to develop a preliminary schedule is to plot the required resources for the planned activities against time (see Figure 16-1). This plot indicates whether the intended implementation program will exceed the available manpower or resources. If it does, two options to solve this problem are available: (i) the schedule can be extended and rearranged so the given resource limit (e.g. 20-person limit, see Figure 16-2) can be observed; or (ii) an increase of the limiting resource may be considered, such as training of additional personnel, development of additional production capacity or increase of capacity of involved institutions. Implementation scheduling should therefore consider such developmental activities and their impact on the implementation schedule and project costs.

Developmental activities also require time and substantial financial investment. Implementation scheduling which avoids peaks in the demand for resources and prudent time extensions represent an important tool to keep project costs as low as possible.

In a further step the preliminary schedule must be tested as to whether all other resource limitations for each activity (such as material supply or available equipment) can be met. Further time extensions and/or program rearrangements may be required in order to come up with a final schedule which considers all resource limitations and other constraints, such as impassable roads during rainy seasons or limited transportation capacity.

Figure 16-1 Schedule with Unrestricted Resources

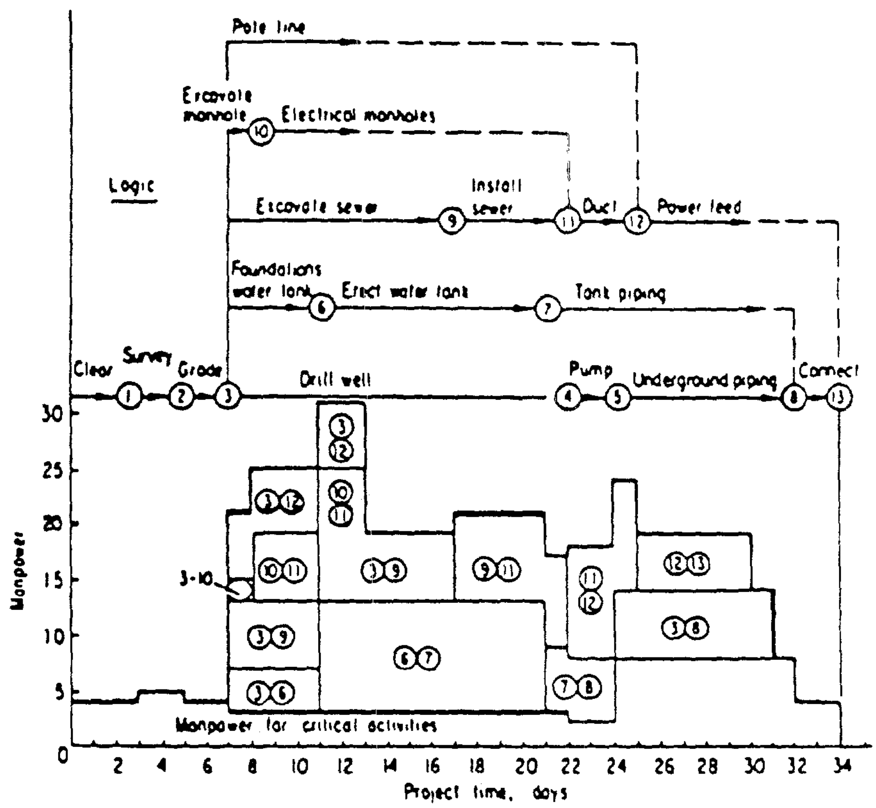
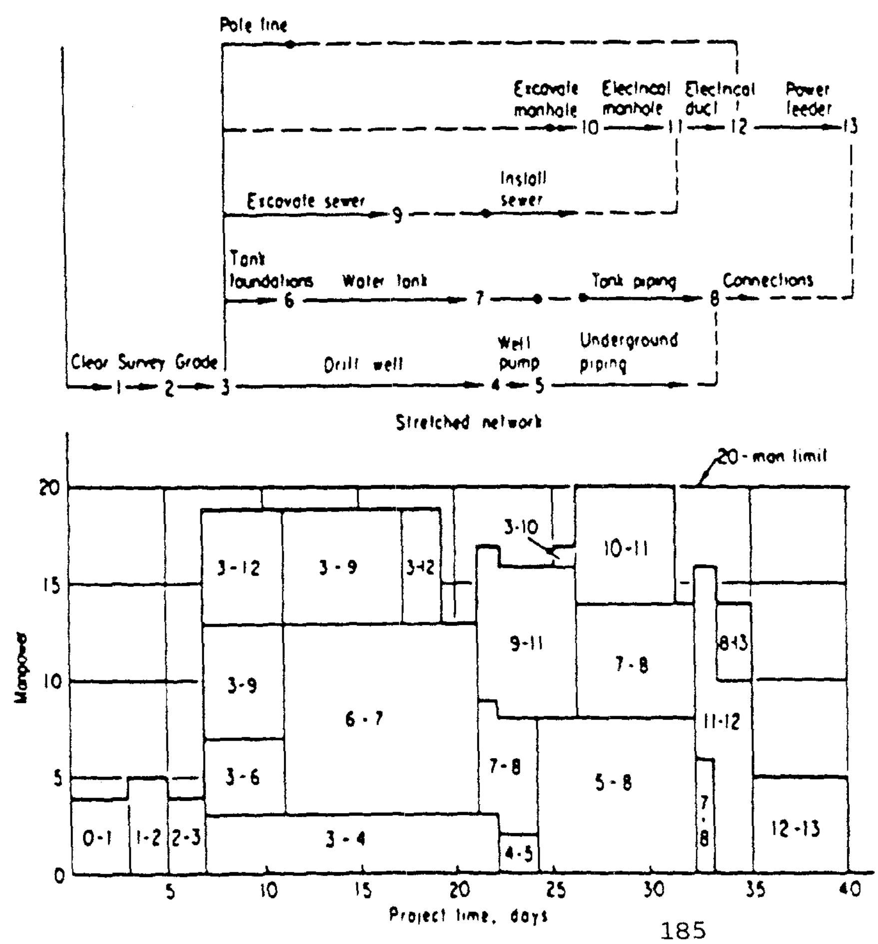


Figure 16-2 Schedule with Restricted Resources



Source: O'Brien (1965)

This schedule can now be used to plan (i) the production and/or procurement of materials and equipment, (ii) the storage and timely distribution of material and equipment, and (iii) the recruitment of personnel, as well as to estimate the required financial resources over time.

For projects involving many small individual systems, this process may be time-consuming, so that a suitable microcomputer and model for resource constraint scheduling may be useful. This preliminary schedule should be updated continually and revised as new information from feasibility studies and construction schedules for individual sub-projects or systems become available.

> **Note:** In this section the local responsible agency should indicate the resources which are likely to be critical and the activities and materials which have to be considered in the implementation schedule based on the local conditions in the project area.

Construction Schedules

The construction phase usually requires the bulk of resources and should therefore be planned and analyzed by a separate construction schedule for each system. The methodology described in the previous section may be used. Table 16-3 shows an example of required activities. Weather conditions may affect the progress and costs of the construction, so to the extent feasible construction activities should be planned during mild and dry seasons.

The construction schedule should indicate when each activity is to be carried out, and the required amount of personnel and critical material and equipment. Figure 16-3 shows an example of such a schedule for the activities listed in Table 16-3, where a town water supply serves several villages.

Data from the final construction schedule can then be used to plan all local activities as well as to update and revise the implementation schedule for the whole project and thereby ensure the timely delivery of required resources.

16.3 Standardization

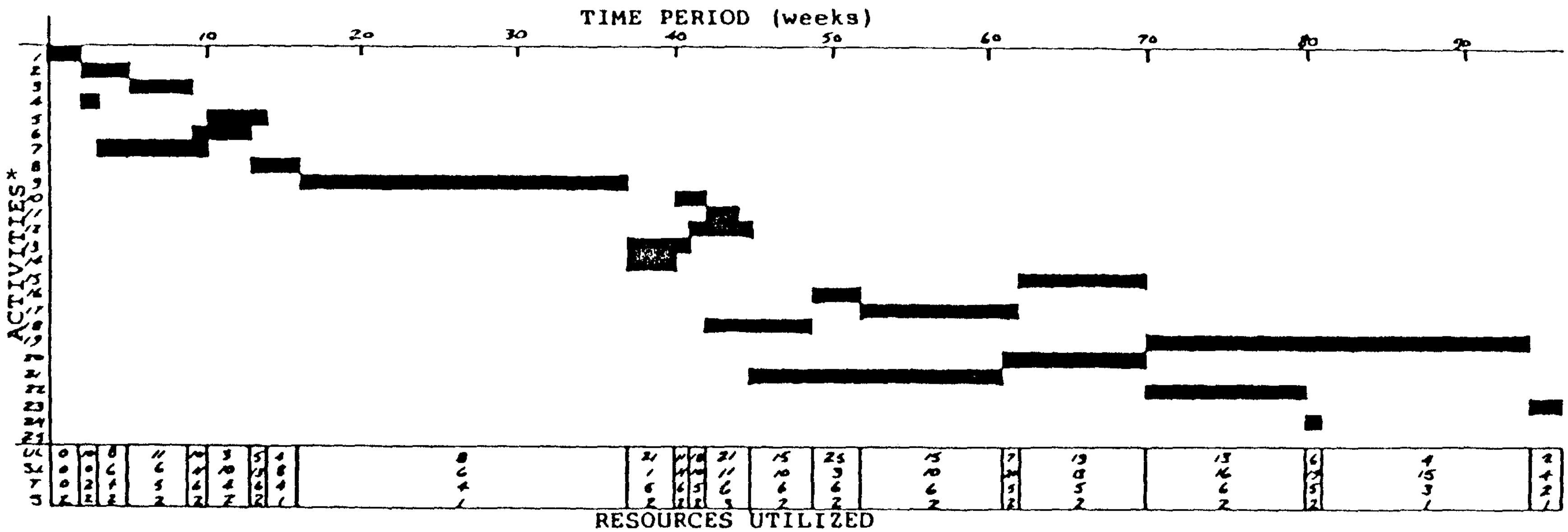
Standardization limits the number of different materials, equipment and designs used for the project, and establishes technical and quality specifications for all these materials, equipment and designs.

Specifications should include: (i) all relevant properties, such as type, size, and capacity; (ii) the required quality and testing procedure to prove this quality; and (iii) other specific requirements, such as pump characteristic curves.

The degree of standardization (number of approved sizes, types or designs) may vary from project to project depending on local physical conditions and economic and logistic considerations.

Standards for materials and equipment should preferably be set at a national level. Very often the standards are based on available equipment and

Figure 16-3 Construction Schedule



UL: unskilled labor in units of 10 men - limit of 25
SL: skilled labor in units of men - limit of 20
T: technicians in units of men - limit of 6
S: supervisors in units of men - limit of 3

* Activities -- see Activity Description Table 16.3

Source: Marinshaw (1983)

Table 16-3: Breakdown of Construction Activities

Activity Description	Duration (weeks)	RESOURCES REQUIRED: Unskilled Labor (men)	Skilled Labor (men)	Technicians (men)	Supervisors (men)
1. Organize work force	2	0	0	0	2
2. Transport supplies to storage	3	0	0	0	1
3. Transport supplies to site	4	30	0	1	1
4. Transport local materials: mainline, intake	1	100	0	2	1
5. Construct intake	4	10	5	2	1
6. Prepare GI pipe	4	20	5	2	1
7. Lay mainline to GI section	7	80	6	4	1
8. Lay GI pipe	3	40	8	4	1
9. Lay mainline: GI section to end	21	80	6	4	1
10. Construct mainline structures	2	20	10	3	1
11. Test mainline	2	20	4	2	1
12. Transport local materials: town reservoirs	4	160	0	2	1
13. Lay branchlines to village reservoirs	4	90	1	3	1
14. Transport local materials: village reservoirs	3	120	0	2	1
15. Transport local materials: town standposts, other	8	150	0	2	1
16. Transport local materials: village standposts, other	3	130	0	2	1
17. Construct town reservoirs	10	30	7	2	1
18. Construct village reservoirs	7	30	7	2	1
19. Construct town standposts, other	24	40	15	3	1
20. Construct village standposts, other	9	40	13	3	1
21. Lay town branchlines	16	120	3	4	1
22. Lay village branchlines	10	90	1	3	1
23. Test town branchlines	2	20	4	2	1
24. Test village branchlines	1	20	4	2	1
25. End of project	0	0	0	0	0

Source: Adapted from Marinshaw (1983)

materials that have been shown to be satisfactory, often manufactured outside the country.

Many countries have established national standards for materials and equipment: the American Water Works Association (AWWA), the British Standards (BS), the German Industrial Standards (DIN), and the Japanese Industrial Standards (JIS). In addition, efforts are under way to unify national standards developed by the International Standards Organization (ISO). Most developing countries use materials built according to one or more of these or other sets of standards. However, the establishment of national standards is required to consider the specific local conditions and needs, and especially to reduce the wide variety of products. In order to facilitate international trade (imports and export of locally produced materials and equipment) such standards should, as far as possible, be compatible with other international standards.

If national standards for major water supply materials and equipment have not been established, they should be developed in conjunction with the proposed project. Standards need to be established at least for the major material components, such as pipes, fittings, valves, water meters and pumps.

Standardized designs and even pre-fabricated standard package plants have been used successfully to minimize planning and construction costs. A reduction in the number of pipe sizes used has only an insignificant effect on network costs (see Table 16-4), but has a considerable potential for cost reduction by reducing the inventory (Hebert, 1985). The best approach to standardized planning and design is through design manuals which specify the available materials, describe the proposed design approach, and provide typical examples. Publications which contain examples of standardized designs are listed in section 4 of the Bibliography. A special publication by the South East Asian Regional Office of WHO is particularly useful (WHO, 1976: "Typical Designs for Engineering Components in Rural Water Supply").

> **Note:** In this section the local responsible agency should list and provide references to the standards and standard designs to be used in the project.

Table 16-4 Per Capita Costs vs. Number of Pipe Sizes (Barangays Anuling and San Roque)

Barangay	No. of Pipe Sizes	Sizes (mm)	Per Capita Costs (P)	% Cost Increase
Anuling	6	75,63,50,38,32,25	16.5	----
	4	75,50,38,25	17.0	0.8
	3	75,50,25	18.1	6.0
San Roque	6	75,63,50,38,32,25	15.2	----
	4	75,50,38,25	15.3	0.1

Source: Hebert (1985)

16.4 Quality and Quality Control

The establishment of standards should be accompanied by a system of quality control. Standards specifications should indicate the testing methods to be used to determine conformity with the standards. The quality control system should ensure that products are in compliance with the standard and its specifications.

Quality is fitness for purpose, entailing reliability, durability, safety, effectiveness, and ease of transport, storage, installation, maintenance, and usage. Poor quality materials, equipment or construction has rendered many water supplies obsolete before or shortly after they became operational. Implementation of a quality control program depends upon the establishment of an adequate organization, preferably at the national or regional level.

Quality Control of Materials and Equipment

Quality control for materials and equipment is best effected by a centralized quality control and assurance system. Most industrialized and several developing countries have accomplished centralized quality control by means of a certification system.

Centralized agencies are set up with testing laboratories and inspection staff which have to ensure the quality of certain products and which are empowered to issue quality certifications for all products which are in compliance. Usually such a certification system is comprised of the following elements.

- Application by the manufacturer for certification of a product complying with existing specifications.
- Development or evaluation of a factory quality control system that guarantees that the product leaving the plant complies with the specifications.
- Negotiations for a contract which gives the manufacturer the right to put the "quality mark" of the agency on the product as long as it is in compliance with the standard.

Such quality assurance procedures can extend over the whole range of the manufacturer's activities. They may include:

- Inspection and testing of raw materials, semi-manufactured products and final products.
- Procedures to ensure: (i) proper operation and maintenance of the production equipment; (ii) adequate training and performance of operators and the quality assurance staff of the manufacturer; (iii) accuracy, calibration and maintenance of testing equipment; (iv) safe storage and transportation of finished products; (v) adequate instructions and support by the manufacturer for the installation, use and maintenance of the product.

In countries where skilled manpower is scarce, the provision of well-developed instructions for installation, testing after installation, and operation and maintenance for products, as well as adequate provision for technical and training support by the manufacturer or supplier at all these stages, are essential to a quality assurance system.

Where no satisfactory centralized quality control and quality assurance system exists, a project-internal quality assurance system is desirable. Special clauses may be included in the specifications of bidding documents which request contractors to comply with the quality assurance program and to provide adequate instructions and technical and training support.

Quality Control of Construction

Quality control and assurance is also required for construction activities. Inaccurate survey instruments and flow measuring equipment may lead to mistakes. Poor installation and inadequate pressure testing of pipelines, as well as poor quality of concrete or steel storage tanks, may lead to leakage.

During the planning stage quality can be improved by:

- regular accuracy tests of survey instruments, laboratory instruments and field equipment such as water metering devices for pumping tests;
- accuracy tests of equipment in existing utilities which are used to collect data for the project (e.g. planning of extensions and rehabilitation);
- field testing and evaluation of standard designs and package facilities by pilot projects and specially designed performance and reliability tests; as well as
- training programs, the development of an appropriate planning manual, and manuals for common survey and test methods.

To improve and assure the quality of construction the following actions may be taken:

- Preparation of design and construction manuals;
- Specifications for all construction work should be included in bid documents and construction contracts;
- Construction activities (either by project staff and local helpers or contractors) should be supervised by resident construction inspectors who have received special training;
- Centralized test facilities for concrete testing should be set up, if not otherwise available in the project area;
- Regular meetings with field staff and contractors may be held to inform and educate project and contractor's staff on relevant measures to ensure the required quality, and to discuss critical issues.

> **Note:** In this section the local manual should indicate the organization and procedures of the local quality control and assurance systems for both materials and construction.

16.5 Design and Construction Manuals

Design and construction manuals will facilitate design and construction; allow standardization of materials, equipment and design; and facilitate the training of engineers, technicians, construction supervisors and quality inspectors.

The design and construction methods presented should, as far as possible, consider local conditions, including locally available materials and local construction practices. The manual should outline all design, construction and material standards to be used by the project and be supported by drawings, figures and examples which illustrate the proposed design and construction methods.

The National Water Resource Council of the Republic of the Philippines (1981) has prepared design, construction and O&M manuals that may serve as guides in the preparation of national manuals.

Chapter 17

Human Resources

The history of community water supply in developing countries is rich in failures, failures which can almost always be traced to inadequate human resources. A report on personnel development in the water sector for the World Bank (Okun, 1977) concluded that: "External financing agencies and the developing countries, with a few notable exceptions, have not yet given attention to human resources development, nor to training, with the result that operations are generally poor. Until attention to human resources development matches the priority given to technical and financial feasibility, particularly in the early stage of a project, little improvement can be expected." Little has changed since 1977; most failures, and there are many, are attributable to inadequate personnel and institutions.

Human resources planning and development should be an integral component of all community water supply projects, going hand in hand with institutional development efforts. Institutional and human resources development must be examined at an early stage of the project development process and should be considered in the framework of a sector plan.

Human resources development involves more than just training people. It should constitute an integrated program to improve the number, skills and productivity, working conditions, and motivation of personnel. A human resources plan should include three integrated components: (i) human resources planning, (ii) training, and (iii) human resources management. The following sections discuss each of these components.

17.1 Human Resources Planning

Human resources planning focuses on logistic aspects of the problem. Its goal is to assess: (i) the human resources needs at project, regional and national levels; (ii) the required training programs; and (iii) the available and required training resources.

This planning process should be carried out at a national or at least regional level, if it has not already been done, to include the needs of existing facilities as well as facilities to be provided by the project and needs for the implementation of the project itself.

Human resources planning includes the following:

Inventory of existing personnel at all skill levels, with the personnel classified in various job or skill categories. Table 17-1 presents an example of a possible classification. The age distribution of the current staff is included to evaluate replacement needs due to retirement. Regional inventories may be required to assess needs in a region.

The inventory should include vacancies, positions held by unqualified personnel, and an assessment of personnel problems, such as shortages of trained staff, low salary levels, unattractive living conditions in rural areas, poor management and staff motivation, undefined career prospects, and lack of opportunities for training and improvement of skills.

Table 17-1 HUMAN RESOURCES INVENTORY

Community or Agency ______________________ DATE: ____________

POPULATION SERVED   HOUSE CONNECTIONS ____________

STANDPOSTS ____________

JOB CATEGORY	Job Classification	Grade	Proposed or Approved Current Establishment	Number in Post According to Age: Under 25	26 - 50	Over 50	Total	Vacancies
1	2	3	4	5	6	7	8	9
A	GENERAL MANAGER							
B	ENGINEERS (Civil & Sanitary)							
	ENGINEERS (Mechanical)							
	ENGINEERS (Electrical)							
	HYDROLOGISTS							
	HYDROGEOLOGISTS							
	TRAINING OFFICERS							
	SENIOR SANITARY INSPECTORS							
	ADMIN./FINANCE OFFICER							
C	TECHNICIANS - Water Resources							
	- Water Supply Design							
	- Laboratory							
	- Operation/Maintenance							
	DRAFTING/SURVEYING							
	SANITARY INSPECTOR/SANITARIAN							
	TRAINING STAFF							
	ACCOUNTING/BOOKKEEPING							
	PURCHASING							
	STENOGRAPHERS							
	CHIEF OPERATORS/SUPERINTENDENT							
	SECRETARY							
D	TECHNICAL OFFICERS							
	JUNIOR SANITARIANS							
	STORE KEEPER							
	CASHIER							
	TYPISTS							
E	ELECTRICIAN							
	MECHANIC							
	PLUMBER/FITTER							
	CARPENTER/MASON							
	WELDER							
	PAINTER							
F	WATERWORKS OPERATOR							
	SANITARY AIDS							
	DRIVERS							
G	LABOURERS							
	GUARDS/WATCHMEN							
	OTHER							
H								
Total								

(1) In the "Number in Post" columns -- (5)(6)(7)(8) -- indicate in brackets the number of expatriates including volunteers, contract employees, etc. working for the agency.

Legend: Job Category:

- A - Senior Management
- B - Profession - Senior Technical/Admin./Clerical
- C - Intermediate - Technical/Admin./Clerical
- D - Junior - Technical/Admin./Clerical
- E - Craftsmen
- F - Operator
- G - Unskilled and semi-skilled
- H - Community-based personnel

Source: Adapted from WHO (1984/2)

Estimate of personnel needs: This estimate should be based on the inventory of existing personnel and the personnel demands of both existing and planned systems. The demands of the new systems should be based on an implementation schedule which indicates when, and how many, new systems are planned to go into operation. The required personnel for operations and maintenance can be estimated by using "personnel (or staffing) ratios" which indicate the local staff needs of systems of various sizes. Personnel ratios and staffing patterns can be developed with the support of personnel specialists.

In general, one person is employed in the water sector for every 1000 people served. For high or more comprehensive levels of service, including sewerage services, the ratio might be one per 500 while for low levels of service, not including sanitation, the requirements might be as low as one per 2000 people served. The distribution of personnel might be as follows:

Top level management and professional	5%
Medium level management	10
Medium level technical	10
Skilled and semi-skilled	45
Unskilled	30
Total	100%

Examples of more specific staffing ratios, in this case for treatment facilities, are shown in Table 17-2. Table 17-3, at the end of this chapter, illustrates staffing recommended for various sizes of water systems in Malaysia. Additional information is provided in a Human Resource Handbook developed by the World Health Organization (WHO, 1984/2).

Planning and construction staff needs may be estimated based on standard estimates for specified facilities, which indicate the personnel needs as a function of size or capacity. Graphical or simple mathematical functions may be developed to simplify these estimates (see Chapter 16).

Estimates should include staff required for project promotion. Well-trained promoters and communicators are important for the success of projects involving small communities. Based on this information, personnel schedules or forecasts should be developed to indicate staff needs for the various stages of the project.

Estimates of training requirements: The required annual recruitment and training needs can be estimated based on the personnel inventory and training needs. Estimates should consider staff attrition and turnover rates.

Assessment of training resources: This inventory should evaluate appropriate local training resources including institutions at all educational levels from universities to on-the-job type training courses offered by existing utilities or other agencies. It might well include an inventory of available local trainers indicating their training and professional experience.

This evaluation should indicate whether the required training capacities can be developed in these institutions with available internal and external funds and training resources. Special assistance for the development of training resources and their funding may be sought from external agencies.

Table 17-2 Operation and Maintenance Manpower Requirements for Water Treatment Plants

Type of Treatment	Size of Community	Manpower Required		
		Unskilled	Skilled	Professional
Slow sand filtration	500 to 2500	1		
(conventional, dynamic)	2500 to 15,000	2		
	15,000 to 50,000	5		
	50,000 to 100,000	8		
Conventional rapid filtration	500 to 2500	1	1	
(conventional, dual-media, upflow-downflow)	2500 to 15,000	1	1	1
	15,000 to 50,000	8	2	1
	50,000 to 100,000	10	3	1
Advanced rapid filtration	500 to 15,000	1	1	1
(multi-media, inclined-plate or tube settling,	15,000 to 50,000	6	2	2
polyelectrolytes)	50,000 to 100,000	10	5	2
Disinfection	500 to 2500	1		
(chlorination)	2500 to 15,000	1	1	
	15,000 to 50,000	2	1	1
	50,000 to 100,000	4	1	1

Source: Adapted from Reid and Coffey, 1978.

Table 17-3 Proposed Staffing Patterns for Water Treatment Plants in Malaysia

Legend

WE	-	Water Engineer
TA	-	Technical Assistant
WPS	-	Water Plant Superintendent
WTPO	-	Water Treatment Plant Operator
PO	-	Pump Operator
ED	-	Engine Driver
MF	-	Mechanical Fitter
CM	-	Chargeman
PL	-	Plant Labourer
SK	-	Store Keeper
LA	-	Laboratory Assistant
FF	-	Fault Finder (electrical)

I. Water Treatment Plants - up to 0.5 mgd (24 hrs. operation)

Management - WE or TA
Person in responsible charge - WPS/Class C
Inspects plant once a week
On call 24 hours a day.

Total Residential Staff

(a) Plant equipped with electric driven pumps located at plant:

1 WPS/Class C (part-time)
4 WTPO
2 PL.

(b) Plant equipped with diesel engine or generator set or either raw or treated water pump station located less than 1/4 mile from water treatment plant:

1 WPS/Class C (part-time)
4 ED/WTPO (appropriate certificate from Machinery Dept. as required)
2 PL.

Table 17-3 (continued)

I. Water Treatment Plants - up to 0.5 mgd (24 hrs. operation) (cont'd)

Shift Distribution

	Case I (a)	Case I (b)
Day	- 1 WPS/Class C (part-time)	1 WPS/Class C (part-time)
	- 1 WTPO, 2 PL	1 ED/WTPO, 2PL
Afternoon	- 1 WTPO	1 ED/WTPO
Night	- 1 WTPO	1 ED/WTPO

II. Water Treatment Plants - 0.5-1.0 mgd (24 hrs. operation)

Management - 1 WE or TA
Person in responsible charge - WPS/Class C
Part-time or full time
On call 24 hours a day

Total Residential Staff

(a) Plant equipped with electric driven pumps located at plant:

1 WPS/Class C (part-time)
1 Asst. WPS/Class C
4 WTPO
2 PL

(b) Plant equipped with diesel engine or generator set or either raw or treated water pump station located less than 1/4 mile from water treatment plant:

1 WPS/Class C (part-time)
1 Asst. WPS/Class C
4 ED/WTPO (appropriate certificate from Machinery Dept. as required)
5 PL

Shift Distribution

	Case II (a)	Case II (b)
Day	- 1WPS/Class C (part-time)	WPS/Class C (part-time)
	- 1 Asst. WPS/Class C	1 Asst. WPS/Class C
	- 1 WTPO, 2 PL	1 ED/WTPO, 2 PL
Afternoon	- 1 WTPO	1 ED/WTPO, 1 PL
Night	- 1 WTPO	1 ED/WTPO, 1 PL

Table 17-3 (continued)

III. Water Treatment Plants - 1-10 mgd (24 hrs. operation).

Management - WE or TA
Person in responsible charge - WPS/Class B
On call 24 hours a day

Total Residential Staff

(a) Plant equipped with electric driven pumps located at plant:

1 WPS/Class B
3 Asst. WPS/Class B
4 WTPO
1 MF
6 PL (depending on size of intake/plant area)

(b) Plant equipped with diesel engine and/or generator set or either raw or treated water pump station located less than 1/4 mile from water treatment plant:

1 WPS/Class B
3 Asst. WPS/Class B
4 WTPO
4 PO/ED (as required by Machinery Dept.)
7 PL (depending on size of intake/plant area)

Shift Distribution

	Case III (a)	Case III (b)
Day	- 1 WPS/Class B - 1 WTPO, 1 MF - 2 PL	1 WPS/Class B 1 WTPO, 1 PO/ED 1 MF, 3 PL
Afternoon	- 1 Asst. WPS/Class B - 1 WTPO, 1 PL	1 Asst. WPC/Class B 1 WTPO, 1 PO/ED 1 PL
Night	- 1 Asst. WPS/Class B - 1 WTPO, 1 PL	1 Asst. WPS/Class B 1 WTPO, 1 PO/ED 1 PL

Source: Adapted from Carefoot (1984)

Measures to improve human resource development efforts may include modifications of existing training programs and curricula of existing institutions to meet priority training needs, and development of short term, in-service training courses in cooperation with existing local and external agencies and utilities.

17.2 Training

The goal of training efforts should be to provide personnel at all skill levels, for project planning, design, construction and operation with the appropriate knowledge and practical skills efficiently and at least cost. To reach this goal the appropriate training approach for each job category should be evaluated. The major steps in developing and conducting training programs (WHO, 1984/2) follow:

Step 1, determination of performance deficiencies and training needs, is essential in connection with training of personnel of existing as well as proposed facilities. It includes an examination of working conditions which may reduce worker motivation and performance.

Step 2, analysis of tasks for training program development, and Step 3 curriculum development, are essential to keep training efforts and costs at the lowest possible level.

Step 4, related to the training setting, also includes the selection and training of trainers, a critical factor in ensuring the success of a training program.

Step 5 is the conduct of the training itself.

Steps 6 and 7, devoted to follow-up of trainees and program evaluation, respectively, are important to improve training quality and efficiency and should be an integral component of all training programs.

Several other points should be considered:

Type of training: Efforts should be focused on training of technicians, operators and administrators, as well as professional personnel.

Appropriate level of technology. Training courses in developing countries should be based on local, rather than foreign, techniques, recognizing the organization and staffing of local educational institutions. The curricula should fit local needs.

Training site and approach. The training site and method (on-the-job, within the local utility or a regional organization, or within a formal educational program at a technical school or university) should reflect local resources in facilities and trainers.

Duration and time arrangement of courses. Courses should be scheduled to encourage maximum participation; either numerous short courses or fewer long courses, or a combination.

Training Aids. Provision and/or development of training aids such as training manuals, job specific manuals, textbooks, reference journals, slides and daylight projection films, and programmed materials (for self-instruction), need to be undertaken as early as feasible.

An International Training Network for Water and Waste Management was established in 1984, with a Coordination Unit located in the World Bank's Water Supply and Urban Development Department in Washington. It is a joint initiative of multilateral and bilateral development agencies in support of the IDWSSD goals. The Network will ultimately consist of at least 15 institutions in developing countries, with each institution having its own

Network Center to carry out training, dissemination of information, and research on low-cost water supply and sanitation.

The Network has produced training films and slide-sound modules. Of particular interest to users of this manual are modules on water supply, including wells and handpumps, gravity flow supplies, water distribution networks and water treatment, the last in preparation.

In addition, the World Bank Economic Development Institute (EDI) has prepared multimedia training modules on planning including such subjects as economic feasibility, with modules on demand forecasting and least-cost analysis; financial feasibility; institutional feasibility, including modules on procurement, consultants, maintenance; and technical options, with modules on groundwater development and rural water supply.

Training is a field which requires not only technical but also communication skills. Agencies with limited training resources or experiences may contact international organizations providing human resource development and training support, such as the World Health Organization, the International Reference Center for Community Water Supply, or the International Labor Organization (for addresses see Annex 1).

17.3 Human Resources Management

Human resources development plans and training programs are likely to have little practical impact if not linked with institutional and management measures which ensure a work environment where the personnel can be motivated, retained and become efficient. Such measures include the improvement of recruitment procedures, staff organization, promotion and career development, and management methods which are able to properly utilize and motivate personnel.

Key elements of human resources management are:

A personnel policy which provides clear rules about recruitment and selection, salary levels and other benefits, performance evaluation, promotion and career development, labor regulations, etc.

An organizational structure which specifies the position and responsibilities of each employee within the organization.

Job descriptions which clearly specify and describe the duties and responsibilities of each employee.

Adequate salary levels and other benefits which can compete with the benefits of similar positions in the private sector.

Satisfactory working facilities and housing conditions which will not result in attrition of the personnel. Proper housing may be of particular importance to keep professional staff in positions in rural areas.

17.4 Human Resources Development Plan

This plan should indicate:

(i) the number of people to be trained annually in different job categories;

(ii) the training requirements in each category;

(iii) estimates of the required initial and recurrent funds;

(iv) estimates of the required additional trainers, training facilities and equipment; and

(v) the required management and institutional measures to motivate and retain staff and increase their efficiency.

To ensure the coordination of complementary efforts, human resources development should be treated as a project component and be managed by a special human resources planning coordinator or coordination team with special knowledge and experience in the training and management field. Such a position or group should be formed in a very early stage of the project as it needs sufficient lead time to assess training needs, plan the training components and ensure and coordinate management support, lead time that may well be longer than required for project design and construction.

Chapter 18

Institutions

Well organized and managed institutions at the local, regional and national level are a precondition for the long-term viability of water supply projects in developing countries. Such institutions should provide technical, logistic and financial support for community water supply systems as well as training opportunities to ensure staff development at all levels.

At the local level, each system should be supported by a local body which represents the interests of the local community and ensures that the system is planned and operated in accordance with their perceptions, needs and willingness to pay or contribute for the services provided.

Improved public health and time and energy savings are the main goals of water supply projects but they can only be achieved if systems are functioning and utilized. The people served by a new or improved system have to perceive its benefits. Health education, promotion and demonstration programs are required to motivate and educate the local community.

In many developing countries water supply institutions are often highly centralized, inefficiently organized, and without adequate human and financial resources to provide reliable service, particularly in rural areas. The offices of water supply authorities are usually located in urban centers and central staff do not have the time or resources to give to rural communities located a considerable distance from headquarters.

The following sections examine measures to improve institutional support. Emphasis is given to: (i) consideration of the local "environment" including political, social, cultural, economic and education aspects; (ii) the decentralization and/or regionalization of institutional structures to support rural and semi-rural communities; and (iii) community participation and factors which tend to influence the willingness to support and maintain an improved water supply system.

18.1 Environmental Analysis

All projects and institutions have to operate under conditions and constraints which lie beyond their direct control. Included are the following: political conditions, the legal framework, existing institutions, socio-cultural and economic conditions, geographic and logistic conditions, and financial and human resources.

Political Conditions

Political factors to be considered at the national level include:

- Political system: Establishes which institutional structures are possible or acceptable. For instance, the level of involvement of the private sector in planning, construction and operation and maintenance, or the degree of decentralization, are affected by the local political philosophy.
- Political commitment, consensus and support for the water supply sector: If these are missing, even strong institutions may have difficulty in mobilizing the required resources. A sector plan and policy at the national level may need to be adopted to get full official support. This should ensure the government's commitment and willingness to provide the required resources.

Legal Framework

An appropriate legal framework should include:

- National, regional and local laws and regulations relevant to: (i) water use, water quality, planning and construction (e.g., standardization); and (ii) administration and operation (e.g., water abstraction and financing, and tariff regulations).
- Appropriateness and enforcibility of existing laws and regulations, whether (i) existing laws may hamper institutional strategies; (ii) new laws and regulations are required; or (iii) the existing or new laws and regulations can be enforced.

The legal framework is discussed further in section 18.2.

Existing Institutions

Existing institutions and their operation at the national, regional and community levels represent conditions which may not fit the needs of the project. Evaluation of existing institutions should include:

- Identification of institutions involved in the water supply sector or related sectors (such as sanitation and public health, including governmental and non-governmental organizations);
- Evaluation of present performance of these organizations, their capacity and capability, including the qualifications of the personnel and management, and their commitment and contributions to the water sector or related sectors;
- Assessment of available financial and technical resources of each institution and whether they are adequate to fulfill the requested functions;
- Identification of critical weaknesses and potential strengths of existing institutions; and
- Evaluation of the coordination and cooperation between existing institutions.

Socio-cultural and Economic Conditions

Socio-cultural and economic conditions have an influence on water use, perceptions of the value of water, and the willingness to support and pay for a community water supply system. Present water use patterns, water-related public health problems, and water availability influence the perceived needs and benefits of an improved water supply system and willingness to pay. The ability to pay or contribute is related to the local economic situation.

Geographic and Logistic Conditions

The level of community dispersion and existing road access should be reflected in the structure of regional institutions, particularly in regard to the provision of logistic support (e.g., required number and locations of regional warehouse and workshop facilities). An evaluation would assess the existing transportation and communication infrastructure in the project region as well as the potential for governmental and other organizations to assist in transporting staff and goods within the region. Close cooperation with other existing institutions may reduce the cost of such support efforts.

Financial and Human Resources

The potential for institutional development rests on scarce national and local financial and human resources. Plans for institutional development must consider the necessary financial commitment for salaries and training from national and regional resources, the available human resources and their proficiency and practical skills at various levels, and the available capacity for training in both public and private institutions. This evaluation should provide a realistic picture of the constraints facing institutional development. These constraints may require staged institutional development, a training component, and adaptation of the existing educational system to the needs of the water supply and public health sector.

18.2 Sector Policy and Strategy

A sector policy and strategy has to be developed before institutional improvements are planned. It should specify the goals of the water supply sector and result in long term plans which indicate how these goals shall be achieved. The sector policy should:

(i) establish guidelines for the approach to be taken to achieve these goals (e.g. community participation, financial self-sufficiency of urban utilities);

(ii) indicate the level and type of support to be provided by central government and its institutions;

(iii) define the responsibilities of the various government agencies and outline required intersector cooperation;

(iv) define the degree of decentralization and the functions and responsibilities of central, regional, and local agencies;

(v) define the role of the private sector (private non-governmental organizations, private industry, private consultants and contractors) in the project planning, construction and operation phase; and

(vi) provide the basis for establishing the required formal legislation and legal framework required to implement, operate and maintain the planned institutions and water supply systems.

The sector strategy should define the institutional structure and the responsibilities of the involved agencies, including local governmental bodies; assess necessary financial and human resources required to achieve the goals set; and the time frame.

An institution and human resources development plan should specify intended institutional development at the central, regional and local level, as well as the planned training efforts, including a timetable for the training of the required personnel and the formation and extension of the planned institutions.

The rules for the selection, support and funding of communities should specify the conditions under which a community will receive support and the way this support will be provided, including a strategy for promotional and educational campaigns in these communities.

If it does not already exist, a legal framework has to be established which supports the actions required to fulfill the goals set by sector policy and strategy. Legislation must be enacted setting up the agencies in charge of the water supply activities. It should: (i) specify the main structure of the agencies and their responsibilities; (ii) define the areas or type of communities to be served; (iii) define the authority and conditions for borrowing or granting money and gathering revenues; (iv) regulate the sources of the required grants and subsidies; and (v) provide the necessary authority to acquire land and other assets required to operate (e.g., employ and train personnel, make contracts, etc.).

Legislation must provide the rights: (i) to take water from appropriate surface and groundwater sources; (ii) to take legal and other actions to protect such sources from pollution; (iii) to acquire land or rights of way by compulsory procedures; and (iv) obtain easements for pipes in roads and other properties. Furthermore, legislation should provide the agencies (or water utilities under their authority) the rights: (i) to charge for the services provided and enforce the payment of charges; (ii) to take action against illegal connections; and (iii) to issue rules for the use of shared public facilities such as public standposts or bath houses.

Examples of sector plans and legal frameworks for the water supply sector can be obtained through the World Health Organization or the World Bank.

18.3 Organizational Structures

This section discusses the organizational aspects of institutional development. A basic concept of successful institutional development is outlined, followed by a discussion of special considerations at different organizational levels.

The Basic Concept

The organizational concept and structure has an impact on the efficiency of the institutions. Where financial and human resources are limited, the institutional framework must optimize their use.

Successful community water supply programs in Africa, Asia and South America have been described by Feliciano (1983), Laugeri (1984), Otterstetter (1983), Strauss (1984), and others. They conclude that effective support of dispersed communities can best be achieved by a combination of centralized and decentralized institutions with clearly defined responsibilities. In most of these countries a three-level structure was used:

- At the national level an agency is responsible for long-term national planning, standard setting, obtaining and distributing financial resources, procurement of imported parts and hiring foreign consulting services, coordinating training efforts, and providing support and advice to the regional agencies.
- At regional or provincial level, usually corresponding to existing administrative state or province structures, organizations (i) develop and finance the projects in their region by following national guidelines and regulations; (ii) supervise and support construction, management, and operation and maintenance of the local systems; and (iii) plan and carry out the required training of local technicians and managerial staff.
- At the local level community organizations are responsible for the management, operation and maintenance of the local system.

Such a decentralized or regionalized structure has a number of advantages over a single central institution:

(i) it simplifies and improves communications and cooperation between local project personnel and local government, particularly where travel distances to central or regional centers would be large;

(ii) it provides a better capability to consider unique local hydrologic, geographic, socio-cultural and economic conditions and constraints;

(iii) it increases the efficiency of skilled manpower, and technical and logistic support, due to reduced communication problems;

(iv) it allows improved integration of local public health and/or non-governmental organizations in regional community water supply projects and programs; and

(v) it can efficiently utilize local potentials of economies and efficiency of scale through development of regional systems, facilities, and/or management.

National Institutions

In many developing countries, national agencies had been responsible for the provision of water supply to rural communities without decentralized support structures. However, such institutions established in several South American countries in the early 1970's (Otterstetter, 1985) found that they lacked adequate structures to handle operation and maintenance activities of the large number of widely scattered community systems, the knowledge to handle local social and cultural problems, and the experience and capacity to handle such local planning, operational and financial activities on a large scale.

Most of these countries have shifted to the more successful three-level organizational structure. The national organizations

(i) promote the importance of water supply within the national government and lobby for commitment and adequate financial support from the national government and international developmental agencies;

(ii) prepare a national sector plan, assist in the development of regional plans and monitor the progress made;

(iii) coordinate the efforts and projects of various agencies and ministries in sector activities at the national level;

(iv) develop standards and guidelines for the selection, evaluation, financing and support of community systems;

(v) promote and organize the education and training of engineers and managers at local and external universities and technical colleges, and support and coordinate training programs by the regional agencies;

(vi) organize and coordinate the local production of water supply materials, and the international procurement of special equipment and spare parts, as well as support from international consulting and development agencies.

These responsibilities should be delegated to one single agency under the direction of competent leadership which has the full support of the responsible ministry.

Several countries (e.g. Philippines, Brazil) created new organizations by legislation which are functionally special national lending institutions for the water supply sector, but also exercise both regulatory and support functions for regional water districts. Other countries delegated part of the development of community water supply to an appropriate ministry, often public health, to an interministerial committee, while they use appropriate organizations at the local level.

Regional Institutions

Regional or district institutions for community water supply may be designed as: (i) state or provisional authorities or agencies; (ii) partly financially autonomous water districts; or (iii) special groups or agencies affiliated with existing regional public health institutions or other related existing regional government institutions (e.g. public works).

The main functions of regional agencies are to:

(i) develop and promote regional programs and projects and evaluate and select communities which fulfill the conditions set for receiving funds and other help for an improved water supply;

(ii) design and construct (or supervise the design and construction of) local community water supply systems;

(iii) provide technical and logistic support (major maintenance and repair jobs, spare parts, fuels, etc.) through regional warehouses and workshops and mobile staff; and

(iv) develop regional training programs and continued education programs in technical, administrative and management skills for regional and local staff.

Regional water agencies may promote and plan the formation of regional water supply systems or utilities. Such systems may take advantage of economies of scale of water treatment facilities, and/or improve the quality and reliability of the supply, if safe and reliable water sources are scarce. Where locally acceptable, regional management of separate systems may decrease operation and administrative costs, and improve the quality of operation and maintenance and the utilization of scarce skilled personnel.

Regional agencies or water districts should be small enough to assure appropriate communication and logistic support, but large enough and financially strong enough to attract skilled management and technical personnel. Regions may include, or be formed around, regional urban centers with an existing water utility. These utilities may be requested or encouraged to assist local community water supply projects with technical, administrative and training support serve as regional support centers.

Local Organizations

Appropriate local organizational structures vary depending on the community size, and the local socio-cultural, economic and political conditions. Under most conditions, the formation of a local water committee responsible for organizing the local support for an improved water supply and its [Aeration and maintenance is an appropriate approach. The ultimate success of a local water supply project depends on the quality of the local institutions responsible for its planning, financing, and utilization.

18.4 Management

The national agency should develop a clear management policy which specifies the function and responsibilities of the various departments, regional agencies, and local water committees or utilities. Management policies which delegate responsibilities to the lowest possible level tend to be most successful. Such a policy should ensure that the local water agencies can operate in a self-reliant, business-like and professional manner; and that the interests of the users of an improved water supply are adequately represented through local water committees. The management policy should further set clear guidelines for planning, evaluation procedures, operational management, financial management and control, personnel management, and marketing.

Operational and Financial Management

For all institutional levels a clear operational and financial management concept needs to be developed. It should include: (i) guidelines and regulations for the technical, financial and administrative planning and operation of a water district or water system; (ii) rules for tendering, bidding, and awarding contracts if the systems are planned and/or constructed by outside consultants and contractors; and (iii) define the function and responsibilities of all personnel by job descriptions.

The conditions to be fulfilled by community committees or local water utilities to obtain financial or technical support from regional or national agencies should be specified. For small communities without existing systems, the formation of a water committee and the selection and training of a local water operator may be required prior to the planning and construction of a water supply system.

The introduction of new improved operational and management rules should be supported by training as well as advisory or audit programs to help local managers and operators develop their knowledge in technical as well as administrative skills (such as accounting, budgeting, inventory control, personnel management and public relations). National agencies should provide such services for regional agencies or water districts while regional offices may provide a similar service for local systems.

Personnel Management

Sound personnel management is a precondition for attracting and retaining skilled personnel and keeping them motivated. It calls for: (i) the provision of adequate salaries at all skill levels to attract and retain experienced people and avoid the corruption problems that are common where salaries are too low to afford an adequate quality of life; (ii) a clearly defined promotion system, which specifies required training, experience, and performance to move up to a certain position; and (iii) the provision of continued training and auditing programs to improve the skills and motivation of the personnel.

18.5 Community Participation

Central institutions alone are not generally able to support large numbers of rural or semi-rural communities with the technical, human and financial resources required for successful long-term operation and maintenance (Laugeri, 1984; Morse, 1985). The long-term success of a water supply system depends on the motivation and ability of the local community to keep their system operational and to improve it continually.

However, establishing strong local community support and participation requires considerable effort that depends on: (i) the need for water and expected and perceived benefits from an improved water supply; (ii) the participation of the local leadership and the involvement of existing social structures and institutions; (iii) the structure of local community organizations responsible for the operation and maintenance of the new system; and (iv) the promotion, education and training efforts in the community.

Need for Water and Expected and Perceived Benefits

People try to optimize the benefits or utility of a service, regardless of the social, cultural and economic setting. These benefits are related to the present availability and need for water. Even within the same community, people of different social groups may have special needs and may value the benefits of safe water quite differently. This is illustrated below.

- Women or children, who spend a considerable amount of their time collecting and carrying water, are likely to value a continuous, convenient, and clean water supply much more than men.

- People with a basic education and understanding of the potential health benefits of clean water will regard an improved, safe water supply as an urgent need and attribute to it a considerable utility. People without such knowledge may attribute more utility to taste and color, based on their traditional understanding of "good" water.

- People with adequate incomes to cover their basic needs, and who can afford the convenience of yard or house connections, may attribute considerable utility to a piped system. However, people with lower incomes may have different priority needs (such as food, clothing or housing) and attribute a lower relative utility to an improved water supply.

These differently perceived utilities can be expressed in the "willingness to pay" or contribute to an improved water supply, which may vary considerably from region to region, or even within different groups of the same community. The resulting willingness to build and maintain a system is shaped by the influence of the several groups in a community.

The success of efforts to develop local institutions depends to a great extent on the identification, motivation, and activation of groups with unreliable or polluted water sources and an organizational structure which ensures that they receive adequate representation and influence in the operation and maintenance of the new system.

Local Leadership, Social Structures, and Institutions

Further important preconditions for success of an improved water supply usually include the support of leaders of a community; the understanding of existing social structures, which may affect access and use of water as well as the local social and political power structure; and identification and involvement of existing local institutions to support and operate a new system.

Local Organization

The type of appropriate local organization depends on community size, the social, political and economic situation, and the presence of existing institutions. Local water committees should be responsible for the local support and communications during the planning and construction phase. Afterwards, they can be in charge of operation and maintenance, as well as for setting and collecting charges required to cover operation and maintenance and repayment of construction funds, and for the training of operators prior to the construction of the system.

Promotion, Education, and Training

Regional promotion, education and training programs are an essential institutional component of a community participation program which ensures self-reliance and viability of small local water systems. Such programs should:

- promote understanding of public health benefits. Particular attention should be paid to the education of water committee members to increase their understanding and motivation. If possible, close cooperation with local public health services should be sought.

- train an adequate number of local personnel or volunteers to operate and maintain new and existing systems;

- provide continuous educational support to improve the skills performance and motivation of local personnel; and
- use pilot projects to promote improved water supply systems and demonstrate their utility and benefits, as well as to train promoters and operational personnel for other systems.

18.6 Conclusion

Successful water supply projects are characterized by the availability of strong institutions; project failures are the result of institutional rather than technical inadequacies.

Bibliography

A) General (Water Supply, Sanitation and Health)

- Cairncross S., Feachem R. (1983)
  Environmental Health Engineering in the Tropics
  John Wiley & Sons Ltd, Chichester, England.

- Feachem R., McGarry M., Mara D. (1977)
  Water, Wastes, and Health in Hot Climates
  Wiley International Edition, Chichester, England.

- Feachem R. et al (1978)
  Water, Health and Development
  TRI-MED Books Ltd., London.

- USAID (1982)
  Safe Water and Waste Disposal for Rural Health: A Program Guide
  U.S. Agency for International Development (AID), Washington, DC.

- USAID (1982)
  Water for the World, Technical Notes
  Volume 1: Human Resources and Rural Water Supply
  Volume 2: Sanitation and Diseases
  U.S. Agency for International Development, Washington, DC.

- WHO (1980)
  Republic of Terrania: A Case Study on the Economic and Financial Aspects of Water Supply and Sanitation Projects
  World Health Organization, Geneva.

- WHO (1981)
  Drinking-Water and Sanitation, 1981-1990; A Way to Health
  World Health Organization, Geneva.

B) Water and Health

- Feachem, R.G. et al (1982)
  Health Aspects of Excreta and Sullage Management
  World Bank, Appropriate Technology for Water Supply and Sanitation Report Series Vol. 3, Washington, DC.

- Hutton, L.G. (1983)
  Field Testing of Water in Developing Countries
  Water Research Centre, England.

- McJunkin, F.E. (1982)
  Water and Human Health
  U.S. Agency for International Development, Washington, DC.

- WHO (1984)
  Guidelines for Drinking Water Quality; Volume 1: Recommendations, Volume 2: Health Criteria and Other Supporting Information Volume 3: Guidelines for Drinking-Water Quality Control for Small Community Supplies
  World Health Organization, Geneva.

C) Water Supply Planning and Design

C1) General

- Cairncross S., Feachem R. (1978)
  Small Water Supplies
  Bulletin No. 10, Ross Institute, London.

- Dangerfield, B.J. (1983)
  Water Supply and Sanitation in Developing Countries
  The Institution of Water Engineers and Scientists, London.

- Dunham, D.C. (1978)
  Fresh Water from the Sun (Solar Distillation)
  U.S. Agency for International Development, Washington, DC.

- Grover, B. (1983)
  Water Supply and Sanitation, Project Preparation Handbook Volume 1: Guidelines; Volume 2: Case Studies (I); Volume 3: Case Study (II, Feasibility Report)
  Technical Paper Nos. 12-14, World Bank, Washington, DC.

- Nissen, E. (1982)
  Rain Catchment and Water Supply in Rural Africa, A Manual
  Hooder and Stoughton, Kent, England.

- Saunders, R.J.; Warford J. (1976)
  Village Water Supply; Economics and Policy in the Developing World
  John Hopkins University Press, Baltimore, Maryland.

- Wagner, E.G.; Lanoix, J.N. (1959)
  Water Supply for Rural Areas and Small Communities
  World Health Organization, Geneva.

- World Health Organization [WHO] (1984)
  Preventive Maintenance of Rural Water Supplies
  WHO, Geneva.

C2) Wells and Handpumps

- Brush R.E. (1978)
  Wells Construction: Hand Dug and Hand Drilled
  Peace Corps, Washington DC, USA.

- Gibson U.P., Singer R.D. (1969)
  Small Wells Manual
  U.S. Agency for International Development (AID), 156 pages

- Hey G.J., Meinardi C.R. (1983)
  A Ground Water Primer
  WHO, IRCWS; Technical Paper Series No 21

- McJunkin, E.F. (1982)
  Hand Pumps for Use in Drinking Water Supplies in Developing Countries
  WHO, IRCWS; Technical Paper Series No 10E, (French and Spanish editions available)

- Stanley, D.; Darrow K. (1977)
  The Arusha Windmill: A Construction Manual
  VITA Publications.

- Watt S.B., Wood W.E. (1979)
  Hand Dug Wells and their Construction
  Intermediate Technology Publications Ltd, London

C3) Water Treatment

- Hey, G.J.; Meinardi, C.R. (1983)
  A Ground Water Primer
  WHO, IRCWS; Technical Paper Series No 21, 119 pages

- Jahn, S.A.A. (1981)
  Traditional Water Purification in Tropical Developing Countries
  German Agency for Technical Cooperation (GTZ), Federal Republic of Germany.

- Schulz, C.R., Okun, D.A. (1984)
  Surface Water Treatment for Communities in Developing Countries
  Wiley-Interscience, New York and Chichester, England.

- van Dijk, J.C., Oomen, J.H. (1982)
  Slow Sand Filtration for Community Water Supply in Developing Countries, A Design and Construction Manual
  WHO, IRCWS; Technical Paper Series No 11E. (French and Spanish editions available)

C4) Design Manuals

- Hofkes, E.H., et al (1981)
  Small Community Water Supplies in Developing Countries
  WHO, IRCWS; Technical Paper Series No 18.

- IRCWS (1980)
  Public Standpost Water Supplies, A Design and Construction Manual
  WHO, IRCWS; Technical Paper Series No 17.

- Jordan, T. D. (1980)
  Handbook of Gravity-Flow Water Systems
  UNICEF, Box 1187, Kathmandu, Nepal.

- Republic of Philippines, Nat. Water Resource Council (1980)
Rural Water Supply: Volume 1: Design Manual; Volume 2: Construction and Installation Manual; Volume 3: Operation and Maintenance Manual

- Republic of the Philippines, Local Water Utilities Administration (LWUA) (1979)
Methodology Manual

- SKAT (1980)
Manual for Rural Water Supply
SKAT (Swiss Center for Appr. Technology), Publication No 8

- Taylor, F.B.; Wood, W.E. (1982)
Guidelines on Health Aspects of Plumbing
WHO, IRCWS; Technical Paper Series No 19.

- UNDP and Republic of Malawi (1982)
Manual for Integrated Projects for Rural Groundwater Supplies
United Nations Development Programme, Lilongwe 3, Malawi

- Van den Heuvel (1981)
Wood and Bamboo for Rural Water Supply
Delft University Press, 2628RT Delft, The Netherlands

- VITA (1977)
Using Water Resources
VITA - Publications

- Watt, S.B. (1978)
Ferrocement Water Tanks and their Construction
Intermediate Technology Publications, London

- WHO (1976)
Typical Designs for Engineering Components in Rural Water Supply
WHO, Regional Publications South-East Asia Series No 2, (distributed by WHO, Geneva, Switzerland)

D) Sanitation Planning and Design

- Bassako, K. et al (1984)
Handbook for District Sanitation Coordinators
World Bank, TAG, Technical Note No. 9

- Feachem, R.; Craincross, S. (1978)
Small Excreta Disposal Systems
Bulletin No. 8, Ross Institute, London

- Kalbermatten, J.M. et al (1980/1)
A Planner's Guide
World Bank, Appropriate Technology for Water Supply and Sanitation, Report Series, Vol. 3, Washington, DC.

- Kalbermatten, J.M. et al (1980/2)
Sanitation Field Manual
World Bank, Appropriate Technology for Water Supply and Sanitation, Report Series, Vol. 11, Washington, DC.

- Mara, D. (1976)
Sewage Treatment in Hot Climates
Wiley International Edition, Chichester, England

- Pacey, A. (1978)
Sanitation in Developing Countries
Wiley International Edition, Chichester, England

- Roy, A.K. et al (1984)
Manual on the Design, Construction and Maintenance of Low-Cost Pour-Flush Waterseal Latrines in India
World Bank, Appropriate Technology for Water Supply and Sanitation, TAG Technical Note No 10

- Rybczynski, W. et al (1978)
Low Cost Technology Options for Sanitation (A State of Art Review and Bibliography
Int. Development Research Centre (IDRC), Ottawa, Canada

- Wagner, E.G., Lanoix, J.N. (1958)
Excreta Disposal for Rural Areas and Small Communities
World Health Organization (WHO), Geneva

E) Socio-cultural Aspects

- Elmendorf M., Buckles P. (1980)
Sociocultural Aspects of Water Supply and Excreta Disposal
World Bank, Appropriate Technology for Water Supply and Sanitation Report Series No 5, Washington, DC

- Simpson-Herbert M. (1983)
Methods for Gathering Socio-cultural Data for Water Supply and Sanitation Projects
World Bank, TAG, Technical Note No 1, Washington, DC

F) Institutional and Human Resource Development

- Abramson, R.; Halsel, W.
Planning for Improved Enterprise Performance; A Guide for Managers and Consultants
Int. Labor Office (ILO), Management Dev. Series No 15, Geneva

- Carefoot, N.; Gibson, H. (1984)
Human Resources Development Handbook
World Health Organization, Geneva

- Glennie, C. (1984)
  A Model for the Development of a Self-help Water Supply Program
  World Bank, TAG, Technical Paper No 2, Washington, DC.

- Perret, H. (1983)
  Planning of Communication Support (Information, Motivation, and Education) in Sanitation Projects and Programs
  World Bank, TAG, Technical Note No 2, Washington, DC

- Perret, H. (1984)
  Monitoring and Evaluation of Communication Support Activities in Low-Cost Sanitation Projects
  World Bank, TAG, Technical Note No 11, Washington, DC

- White A. (1982)
  Community Participation in Water Supply and Sanitation; Concepts, Strategies and Methods
  WHO, IRCWS; Technical Paper Series No 17, Washington, DC

- World Bank (1985)
  The International Training Network for Water and Waste Management
  Water Supply and Urban Development Department, World Bank, Washington, DC.

G) Project Evaluation

- Cairncross, S. et al (1980)
  Evaluation for Village Water Supply Planning
  Technical Papers Series No 15, Wiley International Edition, Chichester, England

- Chauhan, S.K. (1983)
  Who Puts the Water in the Taps?
  International Institute for Environment and Development, London.

- WEDC, (1983)
  Sanitation and Water for Development in Africa
  Proceedings, 9th WEDC Conference, April 1983 in Harare, Zimbabwe, Loughborough University of Technology, UK

- World Health Organization [WHO], (1983/1)
  Minimum Evaluation Procedure (MEP) for Water Supply and Sanitation Projects
  WHO, Geneva

- WHO (1983/2)
  Maximizing Benefits to Health
  WHO, Geneva

- WHO (1983/3)
  Operation and Maintenance of Rural Water Supplies: Eight Questions to Ask
  WHO, Geneva

Cited References

- Austin J.H. et al. (1984)
  Institutional and Human Resources Development for the International Drinking Water Supply and Sanitation Decade
  U.S. Agency for International Development, Washington, DC.

- Cairncross S.; Feachem R. (1978)
  Small Water Supplies
  Bulletin No. 10, Ross Institute, London

- Cairncross S.; Feachem R. (1983)
  Environmental Health Engineering in the Tropics
  John Wiley & Sons Ltd., Chichester, England

- CDM - MEC (1983)
  Report on Unaccounted-for Water Study; Camp, Dreser & McKee, Inc.
  Metropolitan Water Works Authority - Bangkok, Thailand

- Chandler, G.C.(1985)
  How to Achieve Success in Community Water Supply and Sanitation Projects
  World Health Organization, Regional Office for South-East Asia, Delhi

- Dangerfield, B.J. (1983)
  Water Supply and Sanitation in Developing Countries
  The Institution of Water Engineers and Scientists, London

- Deer, R. (1985)
  Water Losses in Distribution Systems in Developing Countries
  Master's Technical Report, (unpublished)
  ESE - University of North Carolina, Chapel Hill, NC, USA

- ENSIC (1983)
  Water Filtration Technologies for Developing Countries
  Environmental Sanitation Reviews No. 12, Bangkok

- Estiada, A.A. (1983)
  Runaway Water: The Lost Resource
  World Water, Nov. 1983, pp. 23 to 25

- Fair, G.M.; Geyer, J.C.; Okun, D.A. (1966)
  Water and Wastewater Engineering
  Volume 1, Water Supply and Wastewater Removal
  John Wiley & Sons, New York

- Feachem, R.; McGarry, M.; Mara, D. (1977)
  Water, Wastes, and Health in Hot Climates
  Wiley International Edition, Chichester, England.

- Feachem, et al. (1978)
  Water, Health and Development
  TRI-MED Books Ltd, London

- Franklin, P. (1979)
  Leak Detection in Water Distribution Systems
  (A Training/Job Manual)
  Pan American Health Organization, Washington, DC

- Giersig, F. (1983)
  Manual for the Preparation of Industrial Feasibility Studies
  United Nations Publication, New York

- Grant, E.L. (1938)
  Principles of Engineering Economy
  Ronald Press Co., New York

- Hebert, P.V.; Lauria, D.T. (1982)
  Optimal Staging and Upgrading of Community Water Supplies and Sanitation in Developing Countries
  ESE - University of North Carolina, Chapel Hill, NC, USA

- Hebert, P.V. (1985)
  Standards and Criteria for Designing Small Urban and Rural Water Supply Systems in the Philippines
  World Bank, Draft TAG - Technical Note, Washington, DC

- Hofkes, E.H. et al. (1981)
  Small Community Water Supplies, Technology of Small Water Systems in Developing Countries
  International Reference Center for Water Supply, The Hague

- Laugeri L. (1984)
  Institutional Development in Rural Water Supply and Sanitation, A Situation Review
  World Health Organization, Geneva

- Lauria, D.T.; Kolsky, P.J.; Middleton, R. (1977)
  Design of Low-Cost Water Distribution Systems
  World Bank, P.U. Report No. RES 11(a), Washington, DC

- Lauria, D.T. (1981)
  Design Guidelines for Low-Cost Water and Sanitation Proceedings of the Convention of the American Society of Civil Engineers, New York

- Lauria, D.T. (1985)
  Revised Design Standards for Community Water Supply Systems in Indonesia
  Proceedings 5th World Congress on Water Resources, Brussels

- Leano, C.L.; de Vera, A. (1983)
  Project Planning Policies for Provincial Water Supply System
  IWSA, Conference Proceedings, 4th Asia Regional Water Supply Conference

- Marinshaw, R.J. (1983)
  Scheduling the Construction of a Rural Water Supply Project with Limited Resources
  Master's Technical Report, ESE, University of North Carolina, Chapel Hill, NC, USA

- McJunkin, F.E. (1968)
Practical Hydraulics for the Public Works Engineer
Public Works Magazine, Ridgewood, New Jersey

- Middleton, R.M.; Shipman, H. (1979)
Pipe Materials and Specifications
World Bank, P.U. Report No. PUN46, Washington, DC

- Morse, E.R.; Gow, D.D. (1985)
Implementation of Rural Development Projects: Lessons from AID and World Bank Experiences
Westview Replica Edition, London

- NWC (1980)
Leakage Control Policy and Practice
National Water Council, London

- O'Brien (1965)
Construction Management
McGraw Hill Book Company, New York

- Okun, D.A. (1977)
Manpower Development and Training in the Water Sector
World Bank, P.U. Report No. PUN 28, Washington, DC

- Otterstetter, H. (1983)
Institutional and Human Resources Development in Water Supply and Sanitation Sector in Latin America
Pan American Health Organization, Washington, DC

- Paul, S. (1984)
Strategic Management of Development Programs
International Labor Office, Geneva

- People's Republic of China (1984)
Rural Drinking Water Manual (Translation)
Office of the Central Patriotic Health Campaign Committee

- Republic of the Philippines (1982)
Rural Water Supply and Sanitation Master Plan
Manila

- Ringskog (1979)
Pragmatic Water Planning
World Health Organization, Geneva

- Saunders, R.J.; Warford, J. (1976)
Village Water Supply: Economics and Policy in the Developing World
John Hopkins University Press, Baltimore, Maryland

- Schulz, C.R.; Okun, D.A. (1984)
Surface Water Treatment for Communities in Developing Countries
John Wiley & Sons, New York and Chichester, England

- Silverman, J.M. (1984)
Technical Assistance and Aid Agency Staff
Alternative Techniques for Greater Effectiveness
World Bank Technical Paper, Washington, DC

- SKAT (1980)
Manual for Rural Water Supply
Swiss Center for Appropriate Technology, St. Gallen

- Sorrels, J.H. (1959)
Manual for Waterworks Operators
The Texas Water and Sewage Works Association

- Strauss, M.; Pun, M.B. (1984)
Community Water Supply and Sanitation Program (Mid and Far Western Development Regions)
Department of Water Supply and Sewerage, Nepal

- Todd, D.K. (1980)
Ground Water Hydrology
John Wiley & Sons, New York

- USAID (1969)
Small Wells Manual; A Manual of Location, Design, Construction, Use and Maintenance
U.S. Agency for International Development, Washington, DC

- USAID (1971)
The Role of Plastic Pipe in Community Water Supplies in Developing Countries
U.S. Agency for International Development, Washington, DC

- USAID (1982)
Water for the World, Technical Notes
U.S. Agency for International Development, Washington, DC

- Wagner, E.G.; Lanoix, J.H. (1959)
Water Supply for Rural Areas and Small Communities
World Health Organization, Geneva

- WHO (1983)
Minimum Evaluation Procedure (MEP) for Water Supply and Sanitation Projects
World Health Organization, Geneva

- WHO (1984/2)
Human Resources Development Handbook
WHO, Division of Environmental Health, Geneva

- WHO (1984)
Preventive Maintenance of Rural Water Supplies
World Health Organization, Geneva

- WHO (1980)
  Republic of Terrania: A Case Study on Economic and Financial Aspects of Water Supply and Sanitation Projects
  World Health Organization, Geneva

- World Bank (1980)
  Water Supply and Waste Disposal
  World Bank Poverty and Basic Needs Series, Washington, DC

- Yassuda, E.R., et al (1982)
  Reduction of Losses and Costs in Water Distribution Systems through Appropriate Technology
  AWWA, Annual Conference Proceedings, Denver, Colorado

- Yepes, G. (1982)
  Least Cost Analysis
  World Bank, EDI-Course Notes Series, CN875, Washington, DC

ANNEX 1

Organizations and Contacts for Water Decade

The official international focal point for Water Decade information is the Programme on the Exchange and Transfer of Information (POETRI) at the International Reference Centre for Community Water Supply and Sanitation (IRC), P.O. Box 5500, 2280 Rijswijk, Netherlands. Tel: 949322; Telex: 33296.

Regional Centers:

AFRICA: Centre interafricain d'etudes hydrauliques (CIEH), BP 369, Ouagadougou, Upper Volta.

ASIA. National Environmental Engineering Research Institute (NEERI), Nehru Marg, Nagpur 440 020, India.

LATIN AMERICA. Centro Panamericano de Ingenieria Sanitaria (CEPIS), CP 4337, Lima 100, Peru.

Centers in Asia, Africa, and Latin America:

Environmental Sanitation Information Center, Asian Institute of Technology, P.O. Box 2754, Bangkok 10501, Thailand.

International Centre for Diarrhoeal Disease Research, Bangladesh. G.P.O. Box 128, Dhaka 2, Bangladesh. Telex: 65612.

Atma Jaya Research Centre, Jalan Jenderal Sudirman, 49a Jakarta, Indonesia, P.O. Box 2639/jkt. Tel: 586491.

AMREF, P.O. Box 30125, Nairobi, Kenya

Oficina regional de ciencia y tecnologia para America Latina y el Caribe (UNESCO-ROSTLAC), Casilla de correo 859, Montevideo, Uruguay.

Centers in Europe

CEFIGRE (International Water Resources Management Training Centre), Sophia Antipolis, BP 13, 06561 Valbonne Cedex, France.

International Reference Centre for Wastes Disposal (IRCWD), Ueberlandstrasse 133, 8600 Duebendorf, Switzerland.

Appropriate Health Resource and Technologies Group (AHRTAG), 85 Marylebone High Street, London W1M 3DE. Tel: 486-4175.

Intermediate Technology Development Group (ITDG), 9 King Street, London WC2E 8HW. Tel: 836-6379.

Water and Waste Engineering for Developing Countries (WEDC), University of Technology, Loughborough, Leics LE11 3TU, UK.

OXFAM, 274 Banbury Road, Oxford OX2 7DZ, UK. Tel: (0865) 56777.

WaterAid, 1 Queen Anne's Gate, London SW1.

Ross Institute of Tropical Hygiene, Keppel Street, London WC1. Tel: 636-8636.

Centers in United States and Canada:

Water and Sanitation for Health (WASH) Project of the U.S. Agency for International Development (USAID), 1611 North Kent Street, Room 1002, Arlington, Virginia 22209, USA. Tel: 703/243-8200. Publishes roster of organizations related to Water Decade, a 90-page document (second edition, November 1983).

Global Water, Suite 300, 2033 M Street NW, Washington, DC 20036, USA.

International Development Research Centre, Box 8500, Ottawa, Canada K1G 3H9. Tel: (613) 235-6163. Telex: 053-3753.

International Agencies

United Nations Children's Fund (UNICEF), United Nations, New York, New York 10017, USA.

United Nations Development Programme (UNDP), Palais des Nations, 1211 Geneva 10, Switzerland. Contact: UNDP/WHO Decade Coordinator; Also UNDP, 1 UN Plaza, New York, New York 10017, USA.

World Bank, 1818 H Street NW, Washington, DC 20433, USA, Water and Urban Affairs Department. Telex: 197688.

World Health Organization (WHO), Avenue Appia 20, 1211 Geneva 27, Switzerland. Tel: 912111. Telex: 27821.

ANNEX 2

Project Data Sheet (with guidelines)

1. Country — 2. No.

3. Title

4. Type of Project

5. Background and Objectives

6. Responsible Government Agency

7. Institutional Support

8. Duration — 9. Starting Date

10. Summary of Estimated Project Costs:

EXTERNAL CONTRIBUTION	NATIONAL CONTRIBUTION	TOTAL

11. Tentative Financing Plan:
    (i) NEEDS   (ii) SOURCES

12. Financial Strategy:

13. Sector Development Performance

14. Outputs

15. Government Priority and Commitment

16. Expected Benefits

17. Prepared by: Date:

Note: This Project Data Sheet has been designed by the World Health Organization in conjunction with the United Nations Development Programme for the International Drinking Water Supply and Sanitation Decade. Copies of the form are available from the Resident Representative of the UNDP or the WHO office in each country.

Source: WHO (Grover, 1983)

GUIDELINES FOR COMPLETING THE PROJECT DATA SHEET

1. COUNTRY: Name of country. State also region where project is implemented.

2. NO: Data sheets will be numbered sequentially for each country as projects are identified and data sheets prepared.

3. TITLE: State full title of project.

4. TYPE OF PROJECT: State briefly the type of project and the principal activities involved; e.g. pre-investment or investment project, financial analysis, tariff study, institutional study, master plan, assistance with operations, technical design, training, improvement of legal framework, research and development, public information, immediate action, community participation, qualitative monitoring and control, local manufacturing, logistics, etc.

5. BACKGROUND AND OBJECTIVES:
   (i) Indicate how the project fits into the country's development programme and its linkages to the sector. Indicate the project's contribution to the country, the economy and the sector.
   (ii) Describe relation of project to other externally assisted projects. State year of start or completion and status of these projects. Indicate donors and external agencies assisting the sector.
   (iii) Indicate if there is community participation and involvement envisaged in project implementation.
   (iv) State and describe existing studies (indicating title and year), as well as data, information, etc. available relevant to the project.

6. RESPONSIBLE GOVERNMENT AGENCY:
   Indicate exact name and address of Government agency responsible for the implementation of the project and to which correspondence should be directed.

7. INSTITUTIONAL SUPPORT:
   (i) Describe existing and expected support for operation and maintenance of systems. Also indicate whether funds have been earmarked for operation and maintenance of systems once they are built.
   (ii) State if project will operate on cost recovery basis. If not, indicate who will pay for the recurrent costs and to what extent.
   (iii) Indicate the type of organization and management available for project implementation.

8. DURATION: Expected duration of project. Duration of each phase if applicable.

9. STARTING DATE: Tentative timing for the start of the project. Also indicate what actions will indicate the start of the project.

10. SUMMARY OF ESTIMATED PROJECT COSTS: State the total cost, in US dollars, of the project and its major components. Indicate the percentage of foreign exchange and local costs for each component as well as the total. If it is a pre-investment or support project rather than an investment project, indicate the following:

National Contributions: (i) Personnel: State number and designation of counterpart national staff assigned to project. Indicate, if possible, their background, experience, etc., and the support they can provide to the project.

(ii) Equipment and supplies: Indicate vehicles, equipment, etc., allotted to the project.

(iii) Funds: Specify contributions to project; in cash and kind, in US dollars.

External Contributions: (i) Personnel: State number, background, and field of expertise required of foreign experts, consultants, etc., with man months in each case.

(ii) Equipment: Indicate if any equipment and supplies are to be provided from external sources.

(iii) Funds: State amount of external funding required in US dollars.

11. TENTATIVE FINANCING PLAN: (only for investment projects)

(i) Needs: State total financing necessary for the project - total estimated cost of the project plus working capital.

(ii) Sources: Indicate sources for the required financing: sector institutions, foreign organizations and the Government.

12. FINANCIAL STRATEGY: (only for investment projects)

Summarize the expected plans and schedule for meeting the project's operating, maintenance and debt service expenses, once implementation is complete.

13. SECTOR DEVELOPMENT PERFORMANCE

(i) Indicate and name how many similar or related projects have been implemented.

(ii) State what Government support has been given to sector development.

14. OUTPUTS: (i) State the nature of studies that will come out of the project. Also improvement in the institutional aspects, etc.

(ii) State investment projects with estimated costs that will come out of the project. Also improvement in the institutional aspects, etc.

15. GOVERNMENT PRIORITY AND COMMITMENT:

(i) Indicate if project is included in Government development plan and country programme.

(ii) Indicate degree of Government priority and commitment to project.

16. BENEFITS: (i) Indicate total population that will be served as a result of the project; also what groups will be the beneficiaries (type of consumer, hospitals, industry, etc.)

(ii) Indicate expected improvement in health and socio-economic conditions.

(iii) Indicate personnel (number, types, etc.) expected to be trained as a result of project and improvement in local sector manpower situation.

17. PREPARED BY: State name of official who completed the data sheet or provided the relevant data for its completion.

Use of Microcomputers

The development of community water supply projects involves a wide variety of engineering and economic analyses. Even for relatively small systems, adequate design and evaluation of least cost solutions by hand calculation can be difficult and time consuming. Microcomputers can simplify and speed up the examination of a wider range of options so that lower cost solutions are more likely to emerge.

Development in the microcomputer sector has increased the capability and affordability of small desk-top computers. A large variety of programs have been and will be developed which can be of considerable assistance in the design and evaluation of community water supply projects.

Table A3-1 lists activities appropriate for the microcomputer. Computer assistance may be particularly useful for the financial feasibility analysis of a large number of systems for the design of distribution networks, and for the analysis of cost data for cost estimates.

The World Bank has supported the development of several computer programs and has helped incorporate them into the planning activities of several water supply agencies in Latin America and Southeast Asia. The programs, except for one, are written in Basic for the use with IBM-PC and compatible microcomputers. All programs are "menu-driven;" a menu guides the user and helps him to input and change data. The following programs which might be appropriate in planning community water supply systems are presently (1985) available:

"REGRESS" is a program for least squares analysis of linear multiple regression problems. This program is particularly useful in developing cost functions for system components.

"BRANCH" is used to design branched water distribution networks by choosing among a set of candidate diameters for each of the pipes such that the total cost of the network is minimized subject to satisfying certain design constraints. The network is characterized by links (individual pipes) and nodes (points of inputs/demands, or pipe junctions). Both the construction cost and the design constraints can be expressed as linear, mathematical statements which can be solved by a technique known as linear programming. The designer proposes commercially available pipe diameters for each link and the linear programming algorithm selects the optimal combination from these candidates. Various sets of pipe diameters for the links are permissible. BRANCH formulates the linear programming model for the least cost design of a branched network, solves the model, and outputs the design as well as corresponding hydraulic information. Data required to run BRANCH are descriptions of the network geometry and topography, the candidate pipe diameters and their costs per unit length, and specifications of the constraints imposed on the design. The program outputs optimal length for the pipes in each link of the network and the hydraulic grade line (HGL) at each of the nodes. A summary of the design characteristics is also given.

Table A3-1

Potential for Computerization in Water Supply Projects

	Computerize (yes/no)
Preinvestment Planning	
Project Identification	no
Pre-Feasibility and Feasibility Study	yes
- service area determination	no
- population projections	yes
- demand projections	yes
- source identification and evaluation	yes
(1) surface water	yes
(2) groundwater	yes
- existing system evaluation (distribution analysis)	yes
- selecting initial service levels and criteria	no
Preliminary Design of Facilities	
- source	no
- transmission	yes
- distribution network	yes
- storage reservoirs	no
- treatment	no
- pumping facilities	no
Cost Estimates and Least-Cost Analysis	yes
Financial Analysis	yes
Implementation	
Detailed Design (distribution and structural analysis)	yes
Construction monitoring	yes

"LOOP" simulates the hydraulic characteristics of a looped (closed-circuit) water distribution network. The network is characterized by links (individual pipes) and nodes (points of inputs/demands or pipe junctions). Data required to run LOOP are descriptions of the elements of the network such as pipe lengths, diameters, friction coefficients, nodal demands and ground elevations, and data describing the geometry of the network. The program outputs include flows and velocities in the links and the pressures at the nodes. The program does not accommodate in-line hydraulic elements such as pumps and valves, nor does it accommodate known hydraulic grade lines for more than one node.

LOOP accepts any looped or looped-and-branched configurations. LOOP's normal use is to simulate the hydraulic response of a network to a single nodal input with a known hydraulic grade line elevation. In addition, LOOP simulates networks with multiple inputs for which a single hydraulic grade line elevation is specified. For multiple input networks, specified inputs need to be available at the pressures determined by LOOP. This may require a trial and error approach. LOOP uses the Hardy Cross algorithm to determine the flow corrections to the assumed flows in each of the links.

"SCREEN" is to be used for the approximate analysis of the financial feasibility of community water supply projects in developing countries. The basic assumptions for SCREEN are that:

a. a preliminary project scheme has been developed;
b. construction costs and other project cost items have been estimated;
c. operation and maintenance costs of the system during its first year of operation have been estimated;
d. the first three years of system operation are the most critical in terms of the system's ability to survive financially, so analysis addresses these years; and
e. financial feasibility is based on all the costs associated with building and operating the system.

"MINTREE" is a program which determines the minimum spanning tree (MST) of any looped or looped and branched network. A MST is a branched network that connects all the nodes in a network such that the total length of the network is minimized. A least cost looped water distribution network is often designed by decomposing the network into a primary branched network that carries most of the flow, and secondary links which provide service to customers not on the primary network. In this sense, a MST can be used to choose the primary distribution network. Such a choice, however, is not always optimal since the MST algorithm considers only length and not flow. Another potential use for this algorithm is to provide a starting condition for hydraulic simulation models of a looped network. The original looped network is reduced to a primary branched network where the flows can be calculated rather easily. The pipes removed from the looped network are then replaced and assumed to carry very small flows. The data required to run MINTREE include the number of nodes, the number of links, the nodes at the end of each link and the length of the link.

"FLOW" is a computer program compiled from FORTRAN for IBM microcomputers and compatibles. The program requires a computer with 256K of memory. This program has been modified from the mainframe version of FLOW. FLOW simulates the hydraulic characteristics of a looped water distribution network. The network is characterized by links (individual pipes) and nodes (pipe junctions or points of inputs or demands). Data required to run FLOW include descriptions of the elements of the network such as pipe lengths, diameters, friction coefficients, nodal demands and elevations, and data describing the geometry of the network. FLOW is capable of including booster pumps, check valves, and reducing valves. The program output includes the flows and velocities in the links and the pressure at the nodes. The data are entered through a separate data file that must be prepared before the program can be run. FLOW develops a nonlinear system of equations which determine flow corrections to be applied to each loop. This flow correction is based on the concept of continuity and that the sum of headlosses around any loop is zero.

These programs and detailed user manuals with examples can be obtained through the World Bank, Technical Advisory Group, Washington, DC 20433, USA. They are not copyrighted and may be modified as required to fit specific local needs.

Additional programs which are commercially available and may be useful in the planning process include:

"Spread sheets." These programs present the user with a matrix which can be filled with text, numbers or mathematical formulas. They are useful for performing standardized financial analyses and in connection with the use of cost functions. Most spread sheets require little programming skill. Some of these programs include the option to present the results graphically and to transfer text and results to other programs.

"Data bases" are programs developed to store, sort and retrieve data. They may be particularly useful in connection with project and cost evaluation where large amounts of data must be analyzed, or to develop inventories and records of materials and equipment.

All these programs have a strong potential to reduce planning and construction costs and provide planners with valuable insights into the sensitivity of project costs due to varying design standards and criteria. However, the use of microcomputers is only feasible in countries and locations where proper service and maintenance for the microcomputers can be assured.

ANNEX 4

Items in Pipe Specifications

Pipe Installation Specifications

I. Earthwork
   A. Classification
   B. Cutting and Breaking Pavement
   C. Trench Excavation
      1. Foundation for pipe
      2. Unsuitable material removed and replaced
      3. Maximum length of open trench
      4. Bracing excavations

II. Open Trench Operations

III. Installation of Pipe
   A. Bedding
      1. Definition
      2. Soft foundations
      3. Placement
      4. Material
   B. Pipe Laying
   C. Field Jointing

IV. Backfill and Densification

V. Field Hydrostatic Testing

VI. Disinfection

VII. Measurement and Payment

Pipe Material Specifications

I. Non-reinforced Concrete Pipe
   A. General
      1. Purpose for which pipe is to be used
      2. Required strength
      3. Reference to standard specifications
   B. Materials
      1. Cement - reference to standard specifications
      2. Aggregates
      3. Gaskets - if applicable
   C. Dimensions and Tolerances
      1. Lengths
      2. Diameters
      3. Wall Thickness
   D. Joints - Acceptable Types
   E. General Manufacturing Requirements
   F. Curing

G. Shop Testing
    1. Load test
    2. Hydrostatic test
H. Causes for Rejection
I. Basis of Acceptance
J. Marking
K. Loading and Shipping

II. Reinforced Concrete Pipe
    A. General - Required strengths and reference to standard specifications
    B. Materials
        1. Cement
        2. Aggregates
        3. Reinforcing steel
        4. Gaskets - if applicable
    C. Dimensions and Tolerances
        1. Lengths
        2. Diameters
        3. Wall thicknesses
    D. Reinforcement
    E. Joints - Acceptable types
    F. General Manufacturing Requirements
    G. Curing
    H. Shop Testing
        1. Load test
        2. Hydrostatic test
    I. Causes for Rejection
    J. Basis of Acceptance
    K. Marking
    L. Loading and Shipping

III. Cast Iron and Ductile Iron Pipe
    A. General - Reference to standard specifications
    B. Pipe Joints
    C. Fittings
    D. Lining and Coating
    E. Polyethylene Encasement for External Corrosion
    F. Marking
    G. Loading and Shipping

IV. Asbestos-Cement Pipe
    A. General
    B. Selection of Design Type
    C. Materials
        1. Statement as to whether autoclaved or not
        2. Gaskets
        3. Coating or lining
    D. Dimensions and Tolerances
    E. Joints
    F. Shop Testing
        1. Hydrostatic proof tests
        2. Hydrostatic bursting strength tests
        3. Crushing strength tests

G. Specials and Fittings
   1. Steel specials and fittings
   2. Cast iron specials and fittings
   3. Outlets
H. Marking
I. Loading and Shipping
J. Basis of Acceptance

V. Steel Pipe
   A. General - Reference standards
   B. Materials
      1. Class of pipe
      2. Grade of steel
   C. Design Criteria
      1. Working water pressure including waterhammer allowance
      2. Backfill
      3. Safety factor
      4. Minimum wall thickness
   D. Dimensions and Tolerances
      1. Diameter
      2. Length
   E. Joints
   F. Specials and Fittings
   G. Welding
   H. Shop Testing
   I. Protective Coating and Lining
   J. Loading and Shipping
   K. Cathodic Protection

VI. Polyvinyl Chloride Plastic Pipe
   A. General
   B. Materials
      1. Plastic compound
      2. Gaskets
      3. Solvent
   C. Test Requirements
   D. Basis of Acceptance
   E. Marking
   F. Loading and Shipping

VII. Reinforced Thermosetting Plastic Pipe
   A. General
   B. Materials
      1. Resin
      2. Glass reinforcement
      3. Filler
      4. Rubber gaskets
   C. Selection and Classes of Pipe
   D. Basis of Acceptance
   E. Joint Design
      1. Rubber gasket joints
      2. Field laminated joints
      3. Mechanically coupled joints
      4. Flanged joints

F. Dimensions and Tolerances
   1. Diameter
   2. Length
   3. Joints
G. Workmanship and Finish
H. Shop Testing
   1. Hydrostatic proof tests
   2. Ultimate hoop tensile strength
   3. Stiffness factor tests
I. Specials and Fittings
   1. Materials
   2. Curves and bends
   3. Outlets
J. Rejections
K. Repairs
L. Marking
M. Loading and Shipping

ANNEX 5

Typical Cost Tables

Typical Unit Costs for Materials, Labor and Transportation

Item	Unit	Unit Price
Sand	cu m	
Cement	cu m	
Reinforcing steel	tons	
Sheet plate	tons	
Timber		
Excavation	cu m	
Backfill	cu m	
Gravel roadway replacement	sq m	
Asphalt roadway replacement	sq m	
Pipe - Plastic		
- 20 mm	m	
- 50 mm	m	
- 75 mm	m	
- 100 mm	m	
- 150 mm	m	
- 200 mm	m	
Pipe - Steel		
- 20 mm	m	
- 50 mm	m	
- 75 mm	m	
- 100 mm	m	
- 150 mm	m	
- 200 mm	m	
Water meters		
- 20 mm	each	
- 50 mm	each	
- 75 mm	each	
- 100 mm	each	
- 150 mm	each	
- 200 mm	each	
Valves		
- 20 mm	each	
- 50 mm	each	
- 75 mm	each	
- 100 mm	each	
- 150 mm	each	
- 200 mm	each	
Labor		
- Engineer	month	
- Technician	month	
- Administrator	month	
- Skilled worker	month	
- Unskilled worker	month	

Transportation	
- Truck:	
Equipment	ton-kilometers
Bulk goods (e.g. chemicals)	" "
Fluids	" "
- Rail:	
Equipment	ton-kilometers
Bulk	" "
Fluids	" "

Example of Project Cost Table, Ground Water Source

Item	Unit	Number or Size	Unit Cost	Total Cost
<u>Water Source</u>				
- Tubewell, lps	each	2		
- Tubewell motors, pumps, and controllers, lps	each	2		
- Master meter	each	1		
<u>Transmission</u>				
- 100 mm dia	m	2000		
- Valves	each			
<u>Treatment</u>				
- Chlorinators	each	2		
<u>Storage</u>				
- Elevated reservoir, 50 cu m	each	1		
<u>Distribution</u>				
- 100 mm dia	m	750		
- 50 mm dia	m	1200		
- 20 mm dia	m	2050		
- Service connections	each	500		
- Service meters	each	500		
Administration Building	sq m	85		
Spare parts and equipment	lump sum			
Subtotal				
Engineering and design				
Physical contingencies				
TOTAL				

Example of Project Cost Table, Surface Water Source

Item	Unit	Number Size, or Capacity	Unit Cost	Total Cost
<u>Water Source</u>				
- River intake	each	1		
- Pumping Station	cu m/hr	10		
<u>Transmission</u>				
- mm dia	m			
- Master meter	each			
<u>Treatment</u>				
- Coagulation-sedimentation	each	1		
- Filtration	each	1		
- Chlorination	each	2		
<u>Storage</u>				
- Ground level reservoir	cu m	200		
- Elevated reservior	cu m	50		
<u>Distribution</u>				
- 100 mm dia	m	750		
- 50 mm dia	m	1200		
- 20 mm dia	m	2050		
- Service connection	each	500		
- Service meters	each	500		
Administration building	sq m	85		
Spare parts and equipment	lump sum			
SUBTOTAL				
Engineering and design				
Physical contingencies				
TOTAL				

Typical Unit Costs for Water Project Components
Community Water Source Systems

Item	Cost per Item[a] (cu m/h) 5	10	15	20	30
Pit, pond or canal intake					
River intake					
Spring catchment					
Tubewell with motor					
- 10-50 m					
- 50-100 m					
- 100-200 m					
> 200 m					

[a]Includes cost of construction, materials, labor, equipment and installation.

Typical Unit Costs for Water Project Components
Water Distribution Systems

Item	Cost per meter[a] (mm) 15	20	30	50	150	200
Plastic pipe						
Steel pipe						
Asbestos cement pipe						

[a]Cost includes pipe material, valves, fittings, excavation, installation and backfill.

ANNEX 6

Representative Cost Data

Table A6-1 Cost Functions

Item	Function	Source
Source	$C = 14{,}000\ P^{0.2}$	Paraguay (1984)
Impounding reservoirs	$C = 1.3\text{x}10^6\ Q^{0.62}$	USA (1981)
	$C = 25\ V^{0.8}$	
Pumping stations	$C = 1.6\text{x}10^6\ Q^{0.7}$	USA (1983)
	$C = 7400\ HP^{0.66}$	Philippines (1979)
(diesel powered)	$C = 9800\ HP^{0.62}$	Philippines (1979)
Pipelines	$C = 380\ L\ D^{1.3}$	USA (1976)
	$C = 320\ L\ D^{1.6}$	Colombia (1979)
	$C = 510\ L\ D^{1.6}$	Brazil (1978)
	$C = 300\ L\ D^{1.6}$	Chile (1979)
	$C = 240\ L\ D^{1.5}$	Peru (1980)
	$C = 540\ L\ D^{1.5}$	USA (1983)
Ground storage tanks	$C = 1200\ V^{0.72}$	USA (1976)
	$C = 690\ V^{0.67}$	Brazil (1978)
	$C = 420\ V^{0.78}$	Philippines (1979)
Elevated storage tanks	$C = 530\ V^{0.88}$	Philippines (1979)
	$C = 189\ P^{0.72}$	Paraguay (1984)
Water treatment plants	$C = 6.8 \times 10^6\ Q^{0.70}$	USA (1976)
	$C = 13.4 \times 10^6\ Q^{0.7}$	USA (1981)
	$C = 2.0 \times 10^6\ Q^{0.69}$	Brazil (1978)
	$C = 3.8 \times 10^6\ Q^{0.77}$	Peru (1980)
Distribution system	$C = 17\ P^{1.1}$	Paraguay (1981)

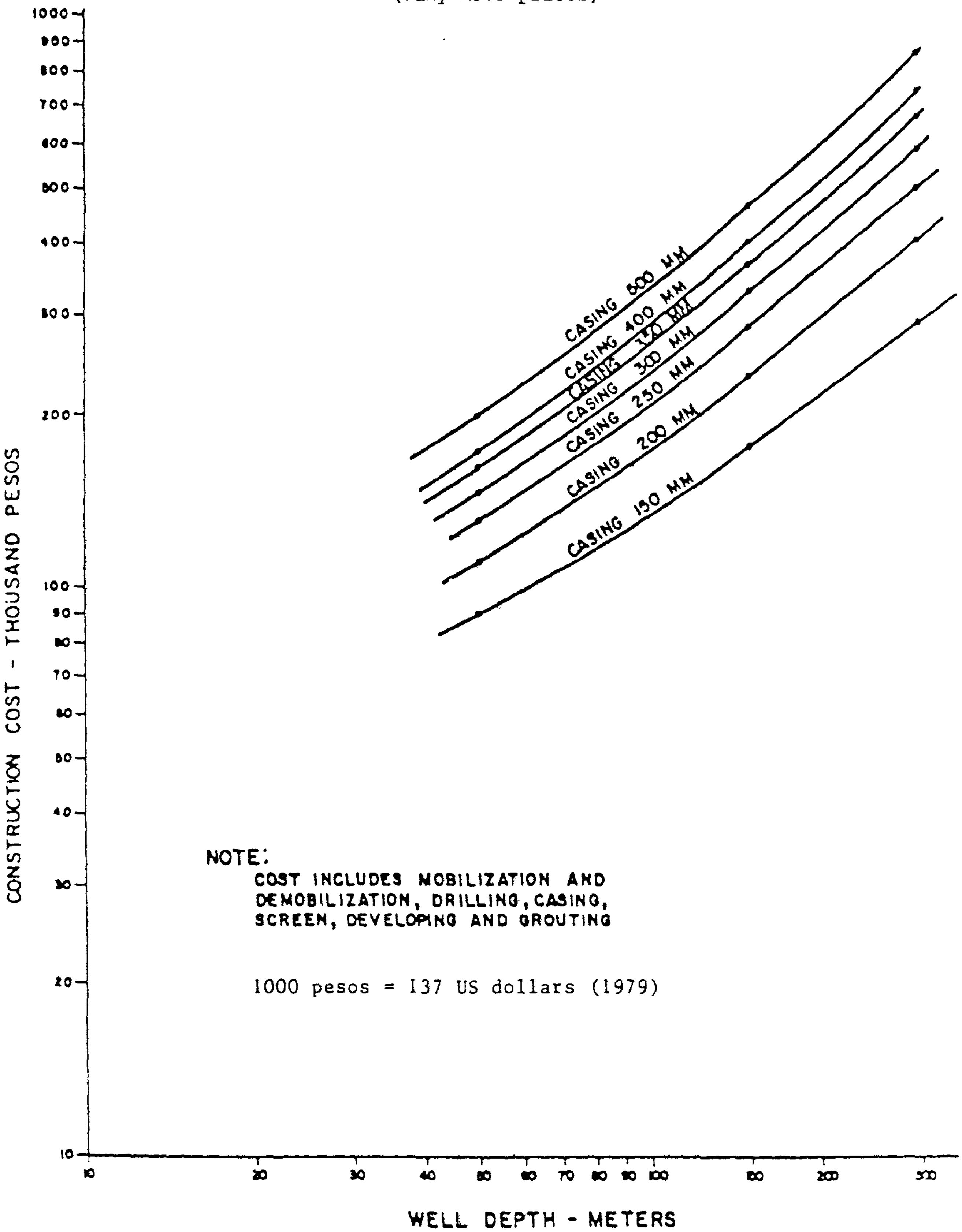
*P, population; HP, horsepower; L, length, m; D, diameter, m; V, volume, m^3; Q, flow, m^3/sec; C, cost, $US.

Note: This table and the figures that follow in ANNEX 6 are not intended to be used as shown. While the exponents may be much the same, the coefficient or unit cost will vary from country to country, and with the year the function was developed. ANNEX 6 provides a model for functions that should be developed in each country from costs experienced in that country as described in Section 15.4.

Figure A6-1

Deepwell Construction Costs

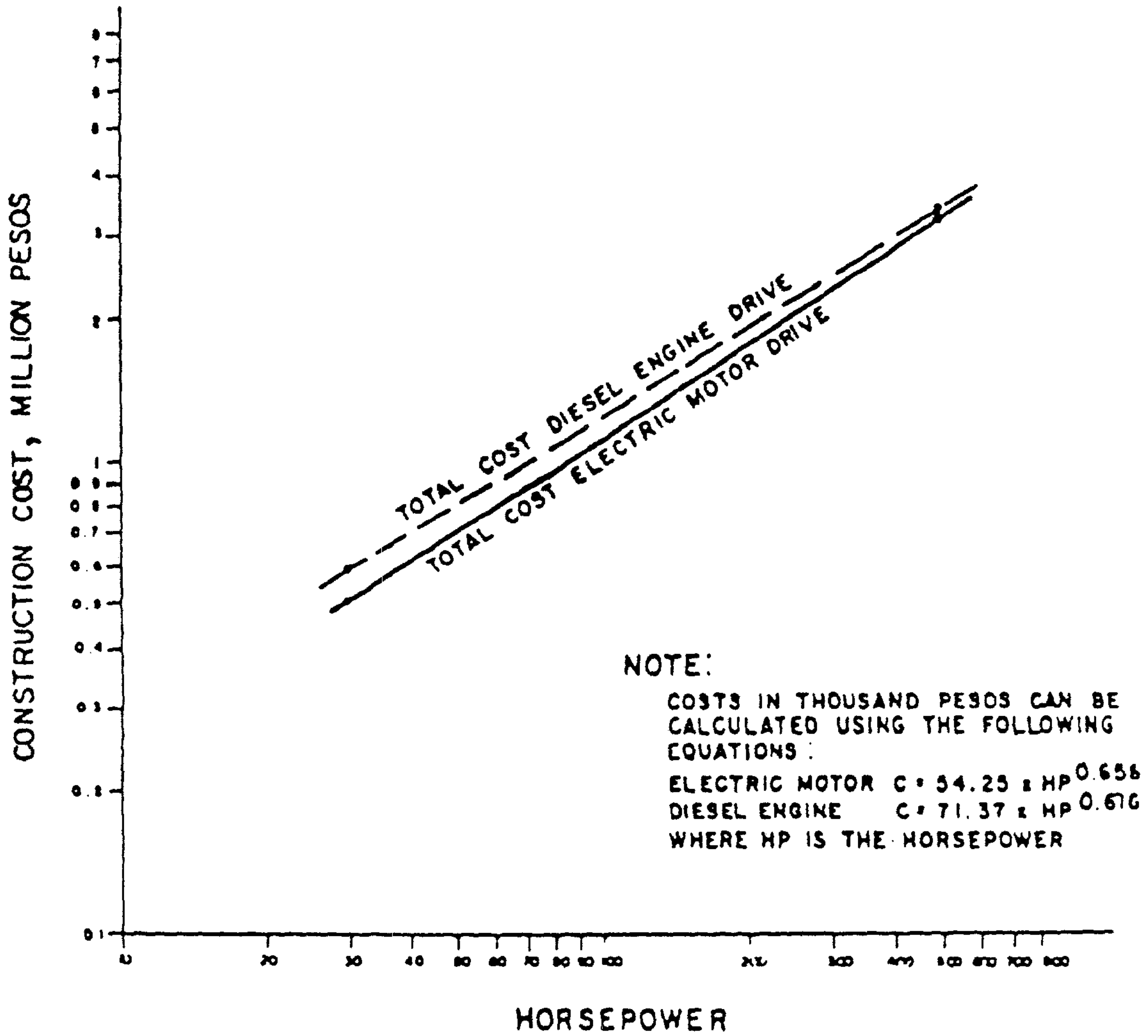
(July 1979 prices)



Source: Republic of the Philippines (1979)
Methodology Manual, Water Supply Feasibility Study
LUWA; Lotti Associates

Figure A6-2

Booster Pump Station Construction Costs as a Function of Horsepower
(July 1979 Prices)

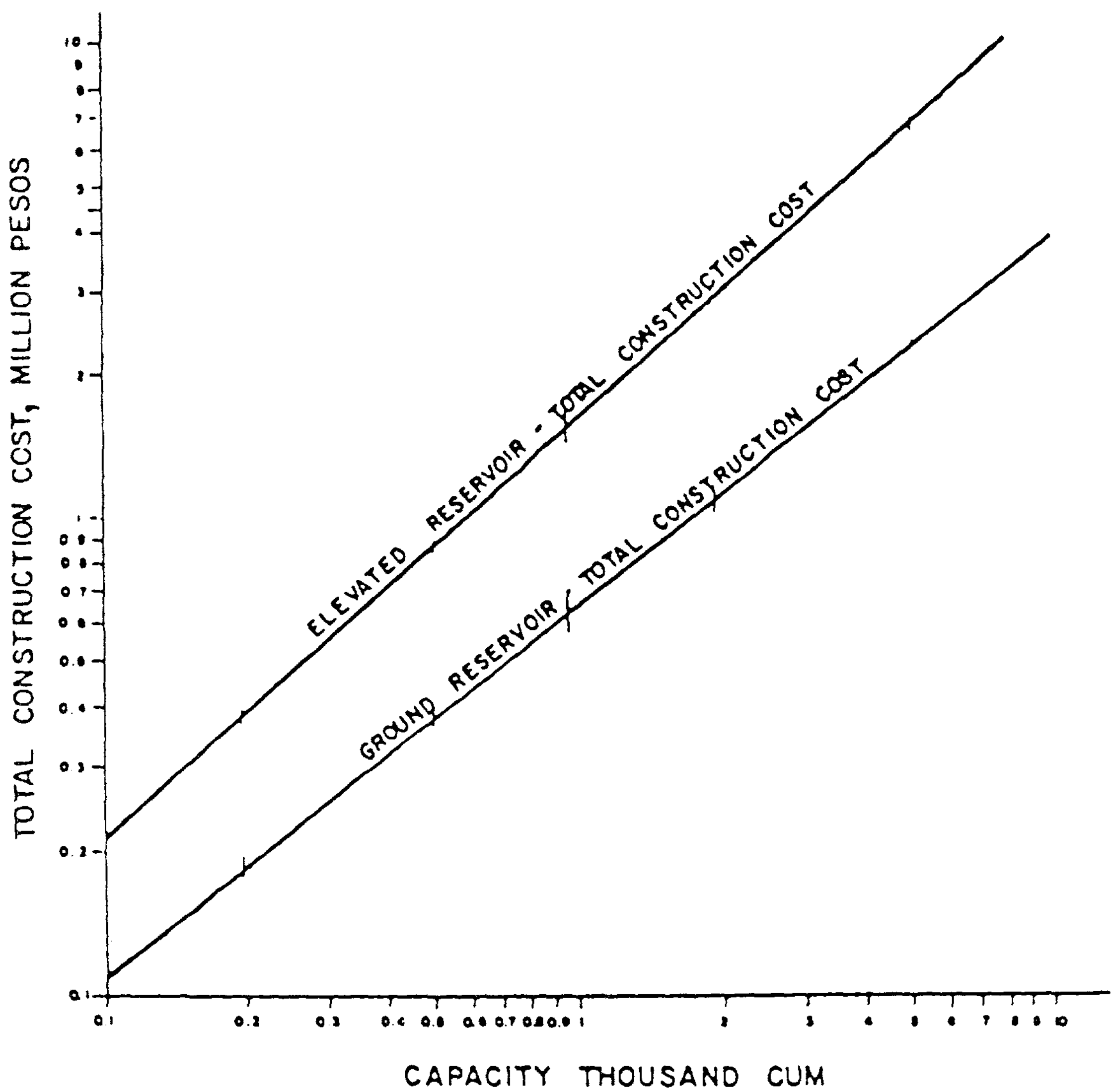


Source: Republic of the Philippines (1979)

Figure A6-3

Construction Costs for Storage Reservoirs

(July 1979 prices)



NOTE:

COSTS IN THOUSAND PESOS CAN BE CALCULATED USING THE FOLLOWING EQUATIONS:

GROUND RESERVOIR $C = 3.10 \times V^{0.776}$

ELEVATED RESERVOIR $C = 3.89 \times V^{0.876}$

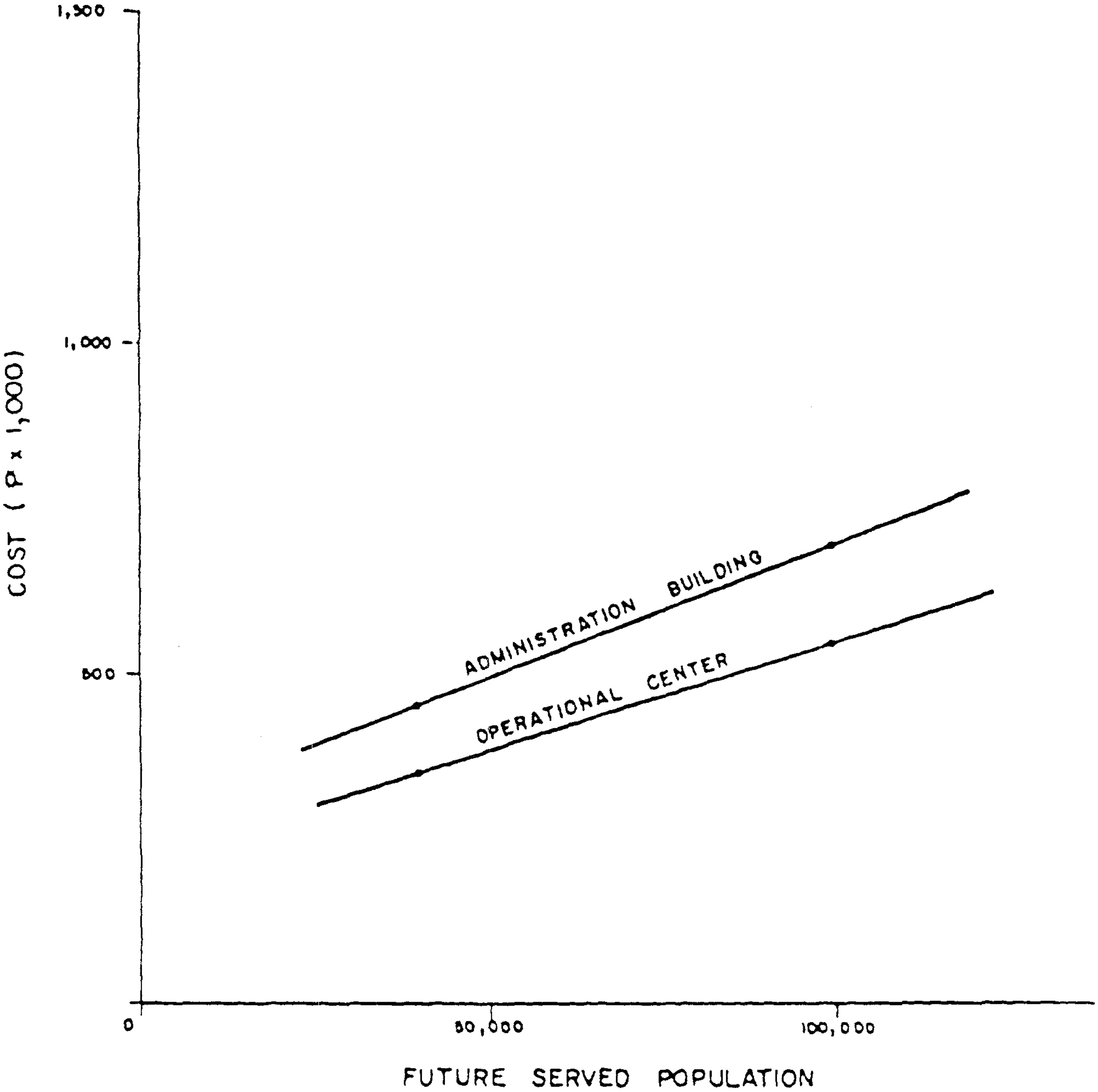
WHERE V IS THE CAPACITY IN CUM

Source: Republic of the Philippines (1979)

Figure A6-4

Management Building Costs

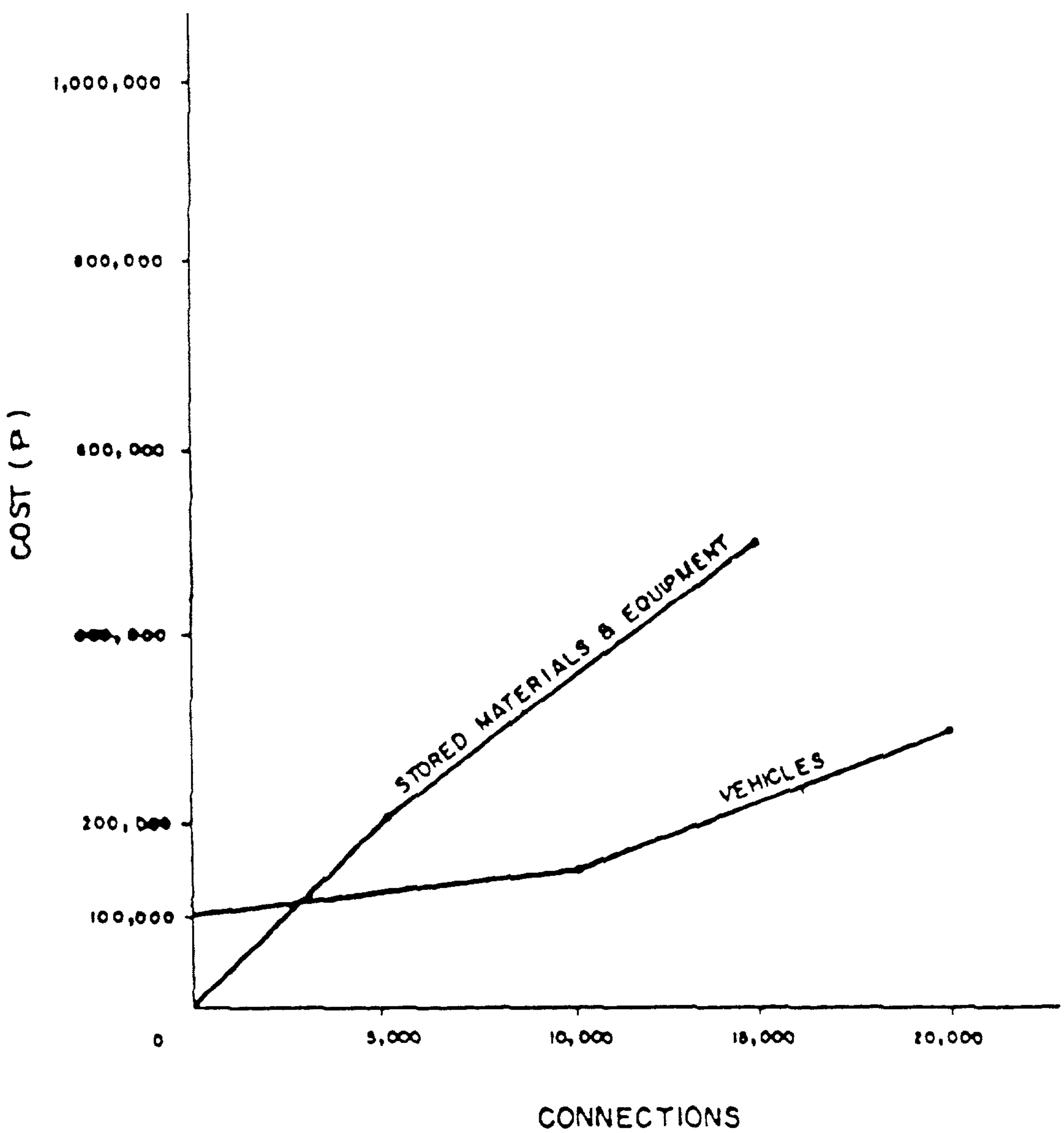
(July 1979 prices)



Source: Republic of the Philippines (1979)

Figure A6-5

Stored Materials and Equipment and Vehicles



Source: Republic of the Philippines (1979)

ANNEX 7

Table for 10% Compound Interest Factors

	Single Payment		Uniform Annual Series				
n	Compound Amount Factor	Present Worth Factor	Sinking Fund Factor	Capital Recovery Factor	Compound Amount Factor	Present Worth Factor	n
	Given P To find S	Given S To find P	Given S To find R	Given P To find R	Given R To find S	Given R To find P	
	$(1+i)^n$	$\frac{1}{(1+i)^n}$	$\frac{i}{(1+i)^n-1}$	$\frac{i(1+i)^n}{(1+i)^n-1}$	$\frac{(1+i)^n-1}{i}$	$\frac{(1+i)^n-1}{i(1+i)^n}$	
1	1.100	0.9091	1.00000	1.10000	1.000	0.909	1
2	1.210	0.8264	0.47619	0.57619	2.100	1.736	2
3	1.331	0.7513	0.30211	0.40211	3.310	2.487	3
4	1.464	0.6830	0.21547	0.31547	4.641	3.170	4
5	1.611	0.6209	0.16380	0.26380	6.105	3.791	5
6	1.772	0.5645	0.12961	0.22961	7.716	4.355	6
7	1.949	0.5132	0.10541	0.20541	9.487	4.868	7
8	2.144	0.4665	0.08744	0.18744	11.436	5.335	8
9	2.358	0.4241	0.07364	0.17364	13.579	5.759	9
10	2.594	0.3855	0.06275	0.16275	15.937	6.144	10
11	2.853	0.3505	0.05396	0.15396	18.531	6.495	11
12	3.138	0.3186	0.04676	0.14676	21.384	6.814	12
13	3.452	0.2897	0.04078	0.14078	24.523	7.103	13
14	3.797	0.2633	0.03575	0.13575	27.975	7.367	14
15	4.177	0.2394	0.03147	0.13147	31.772	7.606	15
16	4.595	0.2176	0.02782	0.12782	35.950	7.824	16
17	5.054	0.1978	0.02466	0.12466	40.545	8.022	17
18	5.560	0.1799	0.02193	0.12193	45.599	8.201	18
19	6.116	0.1635	0.01955	0.11955	51.159	8.365	19
20	6.727	0.1486	0.01746	0.11746	57.275	8.514	20
21	7.400	0.1351	0.01562	0.11562	64.002	8.649	21
22	8.140	0.1228	0.01401	0.11401	71.403	8.772	22
23	8.954	0.1117	0.01257	0.11257	79.543	8.883	23
24	9.850	0.1015	0.01130	0.11130	88.497	8.985	24
25	10.835	0.0923	0.01017	0.11017	98.347	9.077	25
26	11.918	0.0839	0.00916	0.10916	109.182	9.161	26
27	13.110	0.0763	0.00826	0.10826	121.100	9.237	27
28	14.421	0.0693	0.00745	0.10745	134.210	9.307	28
29	15.863	0.0630	0.00673	0.10673	148.631	9.370	29
30	17.449	0.0573	0.00608	0.10608	164.494	9.427	30
31	19.194	0.0521	0.00550	0.10550	181.943	9.479	31
32	21.114	0.0474	0.00497	0.10497	201.138	9.526	32
33	23.225	0.0431	0.00450	0.10450	222.252	9.569	33
34	25.548	0.0391	0.00407	0.10407	245.477	9.609	34
35	28.102	0.0356	0.00369	0.10369	271.024	9.644	35
40	45.259	0.0221	0.00226	0.10226	442.593	9.779	40
45	72.890	0.0137	0.00139	0.10139	718.905	9.863	45
50	117.391	0.0085	0.00086	0.10086	1163.909	9.915	50
55	189.059	0.0053	0.00053	0.10053	1880.591	9.947	55
60	304.482	0.0033	0.00033	0.10033	3034.816	9.967	60
65	490.371	0.0020	0.00020	0.10020	4893.707	9.980	65
70	789.747	0.0013	0.00013	0.10013	7887.470	9.987	70
75	1271.895	0.0008	0.00008	0.10008	12708.954	9.992	75
80	2048.400	0.0005	0.00005	0.10005	20474.002	9.995	80
85	3298.969	0.0003	0.00003	0.10003	32979.690	9.997	85
90	5313.023	0.0002	0.00002	0.10002	53120.226	9.998	90
95	8556.676	0.0001	0.00001	0.10001	85556.760	9.999	95
100	13780.612	0.0001	0.00001	0.10001	137796.123	9.999	100

Source: Grant (1938)

Distributors of World Bank Publications

Algeria: Office des Publications Universitaires, 1, place centrale de Ben-Aknoun, Algiers

Argentina: Carlos Hirsch, SRL, Galeria Guemes, Florida 165, 4th Floor-Ofc. 453/465, 1333 Buenos Aires

Australia, Papua New Guinea, Fiji, Solomon Islands, Vanuatu: Info-Line, Overseas Document Delivery, Box 506, GPO, Sydney, NSW 2001

Austria: Gerold and Co., A-1011 Wien, Graben 31, Austria

Bahrain: Middle East Marketing Research Bureau, Branch *Office: Bahrain Research and Consultancy Associates* W.L.L., P.O. Box 2750, Manama Town 317

Bangladesh: Micro Industries Development Assistance *Society (MIDAS), G.P.O. Box 800, Dhaka*

Belgium: Publications des Nations Unies, Av. du Roi 202, 1060 Brussels

Brazil: Publicacoes Tecnicas Internacionais Ltda., Rua Peixoto Gomide, 209, 01409 Sao Paulo, SP

***Burma.* See Singapore**

Canada: Le Diffuseur, C.P. 85, 1501 rue Ampere, Boucherville, Quebec J4B 5E6

Chile: *Editorial Renacimiento, Miraflores 354, Santiago*

Colombia: Enlace Ltda., Aptdo. Aereo 34270, Bogota D.E.

Costa Rica: Libreria Trejos, Calle 11-13, Av. Fernandez Guell, San Jose

Cyprus: MEMRB Information Services, Head Office, P.O. *Box 2098, Nicosia*

Denmark: SamfundsLitteratur, Rosenoerns Alle 11, DK-1970 Frederiksberg C.

Dominican Republic: Editora Taller, C. por A., Isabel la Catolica a Esq. Restauracion, Apdo. postal 2190, Santo Domingo

Egypt, Arab Republic of: Al Ahram, Galaa Street, Cairo

Fiji. See **Australia**

Finland: Akateeminen Kirjakauppa, P.O. Box 128, SF-00101, Helsinki 10

France: World Bank Publications, 66, avenue d'Iéna, 75116 Paris

Germany, Federal Republic of: UNO-Verlag, D-5300 Bonn 1, Simrockstrasse 23

Greece: MEMRB Information Services, Branch Office, 24, Ippodamou Street, Athens-11635

Hong Kong, Macao: Asia 2000 Ltd., 6 Fl., 146 Prince Edward Road, W, Kowloon

Hungary: Kultura, P.O. Box 149, 1389 Budapest 62

India: New Delhi: *(for single titles)* UBS Publishers' Distributors Ltd., Post Box 7015, 5 Ansari Road, New Delhi 110002; *(for subscription series)* Universal Subscription Agency Pvt. Ltd. (Pending), 18-19 Community Centre Saket, New Delhi 110 017

UBS Branch Offices: 10 First Main Road, Gandhi Nagar, Bangalore 560009; Apeejay Chambers, P.O. Box 736, 5 Wallace Street, Bombay 400001; 8/1-B, Chowringhee Lane, Calcutta 700016; 7/188, 1(CA), Swarup Nagar, Kampu 208002; Sivaganga Road, Nungambakkam, Madras 600034

Indonesia: Pt. Indira Limited, Jl. Sam Ratulangi 37, Jakarta Pusat, PO Box 181

Ireland: TDC Publishers, 12 North Frederick Street, Dublin 1

Israel: Jerusalem Post, Jerusalem Post Building, P.O. Box 81, *Romema Jerusalem 91000*

Italy: Licosa, Libreria Commissionaria, Sansoni S.P.A., Via Lamarmora 45, Casella Postale 552, 50121 Florence

Ivory Coast: Centre d'Edition et de Diffusion Africaines (CEDA), 04 B.P. 541, Abidjan 04 Plateau

Japan: Eastern Book Service (EBS), 37-3, Hongo 3-Chome, Bunkyo-ku 113, Tokyo

Jordan, MEMRB Information Services, Branch Office, P.O. *Box 3143, Jabal, Amman*

Kenya: Africa Book Service (E.A.) Ltd., P.O. Box 45245, Nairobi

Korea, Republic of: Pan Korea Book Corporation, 134, 1-Ka, Shinmun-RO, Jongro-Ku, P.O. Box 101, Kwangwhamun, Seoul

Kuwait, MEMRB Information Services, Branch Office, P.O. Box 5465, Kuwait

Macao. See **Hong Kong**

Malaysia: University of Malaya, Cooperative Bookshop, Limited, P.O. Box 1127, Jalan Pantai Baru, Kuala Lumpur 59200

Maldives. See Sri Lanka

Mexico: INFOTEC, San Fernando No. 37, Col. Toriello Guerre, Thalpan

Morocco: Societe d'Etudes Marketing Marocaine, Branch Office, 2, rue Moliere, Casablanca

Netherlands: Medical Books Europe, BV (MBE), Noorderwal 38, 7241 BL Lochem

New Zealand: R. Hill and Son Ltd., Private Bag, New Market, Auckland

Nigeria: University Press Limited, Three Crowns Building Jericho, Private Mail Bag 5095, Ibadan

Northern Ireland. See **United Kingdom**

Norway: *For single titles:* Tanum-Karl Johan, A.S., Boks Box 1177 Sentrum, 0107, Oslo 1

Pakistan: Mirza Book Agency, 65, Shahrah-e-Quaid-e-Azam, P.O. Box No. 729, Lahore 3

Panama: Libreria Cultural Panamena, S.A. (LCP), Via Espana 16, Panama Zone 1

Papua New Guinea.* See *Australia

Peru: Editorial Desarrollo SA, Apartado 3824, Ica 242, OE. 106, Lima 1

Philippines: National Book Store, P.O. Box 1934, Manila

Portugal: Livraria Portugal, Rua Do Carmo 70-74, 1200 Lisbon

Saudi Arabia: Jarir Book Store, P.O. Box 3196, Riyadh—11471

Singapore, Taiwan, Burma: *Information Publications*, Private, Ltd., 02-06 First Floor, Pei-Fu Industrial Bldg., 24 New Industrial Road, Singapore 1953

Solomon Islands. See **Australia**

South Africa: *For single titles:* Oxford University Press, Southern Africa, Academic Division, P.O. Box 1141, Cape Town 8000. *For subscription series:* International Subscription Serv., P.O. Box 41095, Craighall, Johannesburg

Spain: Mundi-Prensa Libros, S.A., Castello 37, 28001 Madrid

Sri Lanka, Maldives: *Lake House Bookshop, P.O. Box 244*, 100, Sir Chittampalam A. Gardiner Mawatha, Colombo 2

Sweden: *For single titles:* ABCE Fritzes Kungl. *Hovbokhandel, Regeringsgatan 12, Box 16356, S-103 27* Stockholm. *For subscription orders:* Wennergren-Williams AB, Box 30004, S-104 25 Stockholm

Switzerland: Librairie Payot, 6 Rue Grenus, Case postal 381, CH 1211 Geneva 11

Taiwan, China. See **Singapore**

Tanzania: Oxford University Press, P. O. Box 5299, Dar es Salaam

Thailand: Central Department Store, 306 Silom Road, Bangkok

Trinidad & Tobago: Systematics Studies Unit, 55 Eastern Main Road, Curepe, *Trinidad*

Tunisia: Societe Tunisienne de Diffusion, 5 Avenue de Carthage, Tunis

Turkey: Haset Kitabevi A.S., 469, Istiklal Caddesi, Beyoglu-Istanbul

Uganda: *Shipping:* Uganda Bookshop, P.O. Box 7145, Kampala

United Arab Emirates: Middle East Marketing Research Bureau, Branch Office, P. O. Box 6097, Sharjah

United Kingdom and Northern Ireland: Microinfo Ltd., P.O. Box 3, Alton, Hampshire GU 34 2PG

Vanuatu. See **Australia**

Venezuela: Libreria del Este, Aptdo. 60.337, Caracas 1060-A

Western Samoa: Wesley Bookshop, P.O. Box 207, Apia

Yugoslavia: Jugoslovenska Knjiga, YU-11000 BelgradeTrg Republike, 8th Floor

Zimbabwe: Textbook Sales Pvt. Ltd., Box 3799, Harare

No. 33. Guidelines for Calculating Financial and Economic Rates of Return for DFC Projects (also in French, 33F, and Spanish, 33S)

No. 34. Energy Efficiency in the Pulp and Paper Industry with Emphasis on Developing Countries

No. 35. Potential for Energy Efficiency in the Fertilizer Industry

No. 36. Aquaculture: A Component of Low Cost Sanitation Technology

No. 37. Municipal Waste Processing in Europe: A Status Report on Selected Materials and Energy Recovery Projects

No. 38. Bulk Shipping and Terminal Logistics

No. 39. Cocoa Production: Present Constraints and Priorities for Research

No. 40. Irrigation Design and Management: Experience in Thailand

No. 41. Fuel Peat in Developing Countries

No. 42. Administrative and Operational Procedures for Programs for Sites and Services and Area Upgrading

No. 43. Farming Systems Research: A Review

No. 44. Animal Health Services in Sub-Saharan Africa: Alternative Approaches

No. 45. The International Road Roughness Experiment: Establishing Correlation and a Calibration Standard for Measurements

No. 46. Guidelines for Conducting and Calibrating Road Roughness Measurements

No. 47. Guidelines for Evaluating the Management Information Systems of Industrial Enterprises

No. 48. Handpumps Testing and Development: Proceedings of a Workshop in China

No. 49. Anaerobic Digestion: Principals and Practices for Biogas Systems

No. 50. Investment and Finance in Agricultural Service Cooperatives

No. 51. Wastewater Irrigation: Health Effects and Technical Solutions

No. 52. Urban Transit Systems: Guidelines for Examining Options

No. 53. Monitoring and Evaluating Urban Development Programs: A Handbook for Program Managers and Researchers

No. 54. A Manager's Guide to "Monitoring and Evaluating Urban Development Programs"

No. 55. Techniques for Assessing Industrial Hazards: A Manual

No. 56. Action-Planning Workshops for Development Managment: Guidelines

No. 57. The Co-composing of Domestic Solid and Human Wastes

No. 58. Credit Guarantee Schemes for Small and Medium Enterprises

No. 59. World Nitrogen Survey

The World Bank

Headquarters
1818 H Street, N.W.
Washington, D.C. 20433, U.S.A.

Telephone: (202) 477-1234
Telex: WUI 64145 WORLDBANK
RCA 248423 WORLDBK
Cable Address: INTBAFRAD
WASHINGTONDC

European Office
66, avenue d'Iéna
75116 Paris, France

Telephone: (1) 47.23.54.21
Telex: 842-620628

Tokyo Office
Kokusai Building
1-1 Marunouchi 3-chome
Chiyoda-ku, Tokyo 100, Japan

Telephone: (03) 214-5001
Telex: 781-26838

Cover design by Bill Fraser

ISSN 0253-7494
ISBN 0-8213-0896-3