OPERATIONAL GUIDELINES FOR HUMANITARIAN CIVIC ASSISTANCE WATER SUPPLY SYSTEMS

UNITED STATES
SOUTHERN COMMAND

Prepared by

**US Army Corps of Engineers,
Mobile District**

OPERATIONAL GUIDELINES FOR HUMANITARIAN CIVIC ASSISTANCE WATER SUPPLY SYSTEMS

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Acronyms, Abbreviations and Symbols

>	greater than
<	less than
+/-	plus or minus
√	square root
A_f	area of filter bed
amps	amperes
ASTM	American Society for Testing and Materials
A.W.G.	American wire gauge
AWWA	American Water Works Association
bhp	brake horsepower
ºC	degree Celsius
CAC	combined available chlorine
cm	centimeters
cm^3	cubic centimeters
d_{60}	the sieve size through which 60% of the filter material passes
d_{10}	the sieve size through which 10% of the filter material passes
FAC	free available chlorine residual
fps	feet per second
ft	feet
ft^2	square feet
gpcd	gallons per capita per day
gpd	gallons per day
gpm	gallons per minute
HCA	Humanitarian Civic Assistance
HP	horsepower
hr/day	hours per day
HTH	High Test Hypochlorite
Hz	hertz
K	kilograms of chlorine required
kg	kilogram
L/day	liters per day
L/min	liters per minute
L/person/day	liters per person per day
m	meters
m^2	square meters
m^3	cubic meters
m^3/day	cubic meters per day
min	minute
m/hr	meters per hour
m^3/hr	cubic meters per hour
mg/L	milligrams per liter
mL	milliliters
mm	millimeters
m^3/m^2/day	cubic meter per square meter per day
MPN	most probable number
m/s	meters per second
N	number of filters
NEMA	National Electric Manufacturers' Association
NGO	Non-government organization
ntu	nephelometric turbidity unit
PE	polyethylene

pH	potential of Hydrogen
ppm	parts per million
psi	pounds per square inch
PVC	polyvinyl chloride
Q	flow rate
Q_d	daily water demand
Q_{hr}	hourly water demand
SPC	standard plate count
TDH	total dynamic head
U_c	uniformity coefficient (or coefficient of uniformity)
U.S.	United States
USACE	U.S. Army Corps of Engineers
USACHPPM	U.S. Army Center for Health Promotion and Preventive Medicine
USSOUTHCOM	U.S. Southern Command
V	velocity of water flow through the filter bed
V_s	volume of sand in the filter bed
WHO	World Health Organization

FOREWORD

This manual is a continuation of *Operational Guidelines For Humanitarian Civic Assistance (HCA) Water Well Drilling, 2nd edition, June 2001* prepared by the U.S. Army Corps of Engineers (USACE), Mobile District. The well drilling manual provides guidance on well drilling, procedures and installation. The Mobile District recommends that the water supply systems installation be accomplished in a series of exercises. One or two exercises should consist of drilling and testing the well, and the following exercises should provide well pumps, water storage, water distribution systems, water treatment (if required) and operator training.

This manual covers water pumps, treatment, storage, and distribution. The selection of pumps, the depth to set the pumps, the size of the treatment system, and the design of storage tanks cannot be determined until the results of yield and water quality tests are known. Also, the bill of materials for pumps, water treatment systems and water storage tanks cannot be developed until the tests are complete, and the results are reviewed. Plans for potable water systems may have to be approved by local agencies prior to construction. All work should be coordinated closely with the appropriate host nation authorities. Most host nations have their own guidelines and standard operating procedures (SOP), which should be followed as closely as possible for successful HCA projects. A glossary is also included as Appendix A. Useful measurement conversions are included in Appendix B.

The process and completion addressed in this manual outline the objectives to be accomplished prior to turning the completed water systems over to the local township or host nation water authority for operation and maintenance. Training shall also be provided to personnel designated to operate and maintain the water system. An operation and maintenance manual will also be provided.

Any water system that requires abilities beyond the skills of the operating personnel or expenditures beyond the operating agencies budget will result in the system not being maintained. It is important to be certain the water supply systems meet, and not exceed, the economic and professional abilities of the agencies responsible for the system.

Both English and metric units are used throughout this manual. English units are standard for supplies. Pump and piping specifications are expressed in English units in order to provide consistency with manufacturer sizing and publications. Much of the information, particularly figures and tables, was obtained from existing publications and documents. Therefore, the units are variable throughout the manual. Changing the units from the original source document would complicate the tables and figures, creating odd sizes. Where possible, the units are standardized throughout the manual, using metric for field and site work, and English for equipment.

Slow sand filtration units, packaged in kits, will be the treatment of choice for treating water for HCA missions. These commercially available systems are recommended to expedite installation of water treatment systems during exercises. It is anticipated that most water treatment, however, will consist only of chlorination.

This manual is available in digital form, and can be downloaded from the website http://www.sam.usace.army.mil/en/wra/wra.html.

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SECTION 1

PRELIMINARY PLANNING AND DESIGN CONSIDERATIONS

EXECUTIVE SUMMARY

Several steps should be taken when selecting components and designing a community potable water distribution system. Make a site plan indicating the location of the well and locations for water treatment systems, water storage and distribution points. The elements of the water system should be built relatively close to each other. To provide adequate pressure, the ideal location for a ground storage tank is at an elevation 10 meters (m) or more above the outlets for the water distribution system. Locate the outlets for the distribution system at the most convenient location for the population. Coordinate the site plan with the local community and the local water authority. Establish ownership of the new water system and responsibility for operation and maintenance with written agreements, signed by all agencies and appropriate community leaders.

The goal of any water supply exercise is to provide a water system with a minimum of sophisticated treatment requirements. Ideally, simple chlorination will be the only treatment required. The deterioration of watersheds and surface water sources makes proper planning critical. Soil erosion may increase the concentration of suspended solids, complicating water treatment requirements. Industrial and domestic pollution may also contaminate water supplies. Proper site selection and source protection are very important to limit the effects of poor raw water quality. Even with the best site selection and water source protection, sophisticated water treatment may be inevitable for some areas.

1.1 Introduction

The function of a water system is to provide water supply, water treatment when necessary, and water delivery at the time and in the quantity desired. Since the raw water quality and yield of sources, topography, geology, population and intended use of the water may vary, all water systems cannot be alike. Designers and constructors must consider many items when furnishing a water supply system. The following topics are identified and briefly discussed:

Water Quantity Requirements
Water Quality Requirements
Water Sources
Water Treatment
Pumping Requirements
Intake Systems
Water Storage and Distribution
Well Siting Considerations
Treatment System Structure

1.2 Water Quantity Requirements

Early in the planning stage of project development, the designer must obtain an accurate estimate of the amount of water required (gallons per day [gpd]). Normally, the average daily demand is calculated by multiplying the population by an average use per day (gallons per capita per day [gpcd]). The average daily demand is used to assess the ability of available sources to meet continuing demands and to size raw water storage facilities. Raw water storage facilities may be required during extended dry weather. The peak demand must also be calculated to properly size pumps and pipelines, estimate pressure losses, determine water storage requirements, and supply water during peak demand periods. As a general rule, the smaller the water system, the greater the ratio of peak to average demand rates. Thus, the design of small water systems is often influenced more by peak demand than average use. Methods for determining design flow rates differ for various types of water systems and are discussed in more detail in other sections.

1.3 Water Quality Requirements

Water quality requirements are directly related to intended use. Water intended for human consumption requires the highest water quality. The water supplied must meet or exceed appropriate drinking water standards. These standards include microbiological, chemical, radiochemical, and aesthetic requirements that are applicable to water sources as well as finished waters. Some countries have adopted the World Health Organization (WHO) drinking water standards. Others have their own drinking water standards.

Laboratory analyses of water samples are necessary to determine if a proposed water source is or has the potential to be contaminated and unacceptable as a drinking water source. Test wells and sanitary surveys help determine if a potential groundwater or surface water source is acceptable. The local ministry of health should be contacted to obtain minimum test requirements. If the host nation has not adopted a national standard, then the WHO drinking water guidelines should be used as the standard. Individuals with experience in drinking water systems should provide interpretation of the test results.

1.4 Water Sources

1.4.1 Groundwater and Surface Water

The two sources of water for small water systems in developing countries are groundwater and surface water. The final choice will depend on many factors, but the designer should select the source requiring the least treatment. Usually, groundwater is of higher quality and will require less treatment (chlorination only) than surface water sources. Surface water may require treatment beyond chlorination to remove suspended solids. For surface water supply, look for the following characteristics of the ideal small rural water supply watershed:

- clean
- grassed
- free of contamination sources (barns, feedlots, privies, septic tanks, and disposal fields, etc.)
- protected from erosion
- protected from drainage from livestock areas
- fenced to exclude livestock

The following is also suggested criteria for the impoundment or lake:

- At least 8 feet (ft) deep at the deepest point
- Maximum possible water storage in areas more than 3 ft deep
- Able to store at least a one-year supply
- Fenced
- Free of weeds, algae, or floating debris

1.4.2 Sanitary Surveys and Water Source Protection

Sanitary surveys are essential planning considerations for water supply systems. The sanitary inspection consists of a systematic review of the water catchment area (watershed), water source, and water supply system. The inspection should aim at identifying all possible sanitary risks in the catchment area and the water supply system (intake, treatment system, storage, etc.). The sanitary inspection identifies potential risks, and should be conducted frequently in high-risk areas. Adequate protection of the water source is vital for small community water systems.

Examples of sanitary risks are the following:

- Livestock in the catchment area
- Industrial or domestic sources of pollution (particularly pit latrines and septic tanks)
- Rodents
- Cross-connections to sanitary sewerage systems or untreated water

1.5 Water Treatment

The degree of treatment that a given water source will require prior to routine use for human consumption depends primarily upon the initial quality of the water. Since natural water quality may vary widely between sources, and from day to day for a given source, treatment requirements also vary. Place emphasis on simple, low maintenance approaches that require minimal operator time and skill. Operation of complex water treatment facilities represents a major problem for the typical small water system. Thus, careful attention must be given to designing a treatment system that is compatible with the available operation and maintenance resources. This manual describes one method of treatment, slow sand filtration, which is typically suitable for rural water supplies in developing countries. The water treatment method of slow sand filtration is discussed in Section 3.

1.6 Pumping, Storage and Distribution

Pumping, storage and distribution facilities are needed to deliver treated water to users in response to widely varying rates of demand. Since all three components must work together to serve this purpose, the designs must be carefully integrated. Refer to Sections 5, 6, and 7.

1.7 Intake Systems

Intake systems are required to remove the water from the source and deliver it to transmission facilities. Design of intakes is highly site-specific; however, most intake systems can be categorized as either submerged or exposed tower types. Regardless of the system chosen, intakes should be located well away from wastewater or storm water discharges, or other potential sources of contamination. Locate the intake to minimize the uptake of silt, sand, and debris. Provide for cleaning or other maintenance of the structures.

Other factors that may impact on the design of intakes are the following:

- type of source
- water depth
- bottom conditions
- navigation requirements
- effects of floods, currents, and storm or bottom conditions
- exposed structures and pipelines

1.8 Well Location

Well sites should be selected by a qualified geologist following a field investigation. Selecting a water well location is not an exact science. The two most critical parameters for well location are encountering a quality groundwater source and producing a sufficient quantity of water. Well data from existing wells in the area should be a good indication of the water yield, water quality, depth to the aquifer, and seasonal changes in the aquifer. Test wells should be installed to determine locations for permanent wells. All well sites should be above flood elevations. Look for high water marks and persons with local knowledge on high water elevations. Runoff and drainage must be diverted around or away from the wellhead to help reduce the possibility of surface contamination.

To reduce sources of contamination, well sites should be uphill and meet the following minimum requirements:

- 50 m from a seepage pit or cesspool
- 30 m from a subsurface absorption system
- 30 m from a pit toilet
- 30 m from animal pens, barns, or silos
- 15 m from a septic tank
- 7 m from a drain, ditch or house foundation

1.9 Treatment System Structure

If water treatment is required in addition to chlorination, a structure with a roof may be required to house smaller treatment systems. This structure should be located in proximity to the wellhead. Controls for the well pump should be located in this structure, if possible. Runoff and drainage must be diverted around or away from the treatment system structure. The structure should be above the highest flood elevation and sited at least 7 m from any surface drainage ditches or swales. The structure should also be encircled by at least a 6-ft high chain link fence for security.

1.10 Water Storage Tanks

Water storage tanks should be constructed on the highest surface elevation available. The ideal elevation for an above ground storage tank is 10 meters above the outlets for the water distribution system. Ten meters is the minimum elevation recommended to provide adequate pressure for the water distribution system. The outlets for the distribution system should be located at the most convenient location for the population. Refer to Section 6 for tank sizes and locations, and detailed discussion of storage tanks.

1.11 Water Distribution System

Water lines shall be installed to connect the well or treatment system to the water storage tank and the storage tank to the distribution points. In general, follow the path of least resistance and provide a minimum of 750 millimeters (mm) earth cover over the top of the water line. Installing a distribution line from the tank to the road, and installing outlets for individual use is adequate in many cases. See Section 7 for detailed discussion of water distribution systems.

SECTION 2

DRINKING WATER TREATMENT

EXECUTIVE SUMMARY

Water should never be presumed safe for drinking purposes until it has been at least minimally tested and approved. This section discusses issues associated with the testing of water and limited treatment options. It lists many of the known water related diseases, whether water-borne and resulting from ingestion of pathogens or the lack of safe water to provide for adequate hygiene. A discussion is provided that recounts the factors that must be examined when choosing a treatment technology, such as available project funds, construction cost, training of personnel, and operation and maintenance requirements. Short discussions are provided that discuss simple treatment technology to more complex methods such as desalination and conditioning. Selection criteria are provided for planning purposes for classifying a water source ranging from excellent to rejectable. Guidance is provided on the analysis of a water sample, especially in regard to bacterial analysis, which is the number one cause for rejection of a water source.

2.1 Introduction

In developing countries, it is imperative that planners, engineers, and constructors not overdose communities with capital-intensive methods of water treatment. Techniques used in industrialized nations, when applied to developing countries, should address the necessary management requirements, education level of operators, and procurement of spare and replacement parts. If these items are not considered in pre-planning, it is likely that a system within a few years (or less) of construction will be found virtually inoperative. Treatment in a developing country should include alternative water treatment practices that minimize the need for importing equipment, materials and people. In a statement to the United Nations Economic and Social Council on March 26, 1965, the president of the World Bank, George D. Woods, stated the following:

> "Neither general programs nor even generous supplies of capital will accomplish much until the right technology, competent management, and manpower with the proper blend of skills are brought together and focused effectively on well-conceived projects."

These considerations are factored into the recommendations that are provided herein. It is more than just a matter of having clean and safe water to drink. The lack of clean and safe water supplies create conditions that hamper the development of good hygiene and prevent sanitary conditions in populated areas.

The most effective way to ensure safe and acceptable drinking water for consumers is to provide for a multiple-barrier concept. This concept is considered by public health and water supply professionals as the traditional approach and is used in more industrialized nations as a standard of practice and environmental regulation. Water source protection, effective treatment processes, and proper integrity and management of the distribution system provide multiple-barrier protection. Poor quality of the water source will require a higher level of water treatment. By optimizing the performance of each barrier, a reasonable assurance exists that a waterworks system can provide quality drinking water to all consumers at all times. The general level of hygiene in a community is absolutely essential in protecting water sources and developing quality water supplies. It is useless to focus on water quality if excreta is scattered everywhere, posing a threat to any newly purified water. Table 2 - 1 illustrates the cause and effect relationship of problems created by unsafe drinking water or an inadequate supply of safe water.

Water contaminated by human, chemical or industrial wastes can cause a variety of communicable diseases through ingestion or physical contact. Examples of such diseases are listed below:

- **Water-borne diseases**: caused by the ingestion of water contaminated by human or animal feces or urine containing pathogenic bacteria or viruses; include cholera, typhoid, amoebic and bacillary dysentery and other diarrhea diseases.

- **Water-washed diseases**: caused by poor personal hygiene and skin or eye contact with contaminated water; include scabies, trachoma and flea, lice and tick-borne diseases.

- **Water-based diseases**: caused by parasites found in intermediate organisms living in water; include dracunculiasis, schistosomiasis and other helminths.

- **Water-related diseases**: caused by insect vectors that breed in water; include dengue, filariasis, malaria, onchocerciasis, trypanosomiasis and yellow fever.

No single type of intervention has greater overall impact upon the national development and public health than the provision of safe drinking water and the proper disposal of human excreta. The direct effects of improved water and sanitation services upon health are most clearly seen in the case of water-related diseases, which arise from the ingestion of pathogens in contaminated water or food and from insects or other vectors associated with water. Improved water and sanitation can reduce morbidity and mortality rates of some of the most serious of these diseases by 20% to 80%.

Table 2 - 1 Estimates of Morbidity and Mortality or Water-Related Diseases

Disease	Morbidity (episodes/year)	Mortality (deaths/year)	Relationship of Disease to Water Supply and Sanitation
Diarrhea diseases	1,000,000,000	3,300,000	Strongly related to unsanitary excreta disposal, poor personal and domestic hygiene, unsafe drinking water
Infection with Intestinal Helminths	1,500,000,000	100,000	Strongly related to unsanitary excreta disposal, poor personal and domestic hygiene
Schistosomiasis	200,000,000	200,000	Strongly related to unsanitary excreta disposal and absence of nearby sources of safe water
Dracunculiasis	100,000	-	Strongly related to unsafe drinking water
Trachoma	150,000,000	-	Strongly related to lack of face washing, often due to absence of nearby sources of safe drinking water
Malaria	400,000,000	1,500,000	Related to poor water management, water storage, operation of water points and drainage
Dengue Fever	1,750,000	20,000	Related to poor solid wastes management, water storage, operation of water points and drainage
Poliomyelitis	114,000	-	Related to unsanitary excreta disposal, poor personal and domestic hygiene, unsafe drinking water
Trypanosomiasis	275,000	130,000	Related to absence of nearby sources of safe drinking water
Bancroftian filariasis	72,800,000	-	Related to poor water management, water storage, operation of water points and drainage

Source: WHO data 1998
- information not available

It is abundantly clear from the information in Table 2 - 1 that a clean and safe water supply is not only an absolute necessity, but also a moral imperative. The effect of an unsafe water supply usually strikes the very young and elderly first.

Water may need treatment before it can be used for human consumption. Water treatment in rural areas must stress bacteriological treatment, the pathogen removal through filtration, and chemical disinfection. Clarification processes are used to remove suspended matter. To remove certain dissolved chemicals and minerals, water conditioning is needed. Conditioning requires expensive equipment and chemicals and is usually not practical for rural areas.

Water subject to bacteriological contamination and turbidity must be either protected from the contamination or treated. Groundwater is usually protected from contamination naturally. However, if wells are located near latrines or other sources of contamination, or near limestone or other fractured rock, water quality is questionable. If water sample analysis or a sanitary survey shows bacteriological contamination, the water must be treated.

Treatment of surface water is almost always necessary to ensure quality. Unlike groundwater, surface water is not protected from contact with people, animals, and surface run-off that can introduce disease-causing organisms. This section discusses the basic factors, that must be considered when planning a water treatment system, and the treatment process or mix of processes that best meets the needs of the community.

2.2 General Considerations

The addition of any type of treatment to a water system increases the cost of developing the system, the amount of maintenance required, and the risk of breakdown.

If water treatment is necessary, the following factors must be considered when choosing which treatment system to use.

- **Amount of funds available for the project.** Most rural communities have limited funds and cannot afford expensive treatment methods. The choice between a treated and an untreated source and the choice of a treatment technique depends on the funds available.

- **Cost of construction.** The construction of a water treatment facility is expensive. Construction costs must be determined before deciding to use a specific process. Compare the construction costs of the processes that will provide the same treatment. Also, compare the costs of developing alternative water sources. For example, a water source needing treatment is located near a village and a source needing no treatment is further away. The cost of installing a pipeline and pumping the water from the source needing no treatment to the village may be less than the cost of developing a treatment system for the closer source. If the pipeline is cheaper or the difference in cost is not great, the development of the longer pipeline may be the better alternative.

- **Availability of trained personnel or the likelihood of establishing the necessary training programs.** Trained personnel are needed to operate and maintain water treatment systems, and the success of the water treatment depends on their skill. If trained personnel are not available or are poorly trained, the water treatment system will not function properly, water quality will be poor, and the benefits of money spent on construction will be lost.

- **Cost of operation and maintenance.** The cost and availability of chemicals such as chlorine for treatment, energy to run pumps, and salaries for workers must be determined. The total cost may be beyond the means of the community. Chemicals and spare parts must be readily available to avoid closing down the treatment system or operating it without the required equipment and materials.

The general policy should be that a water source needing no treatment is preferable in rural areas. By selecting a source of water that needs no treatment, a community can save money and have a water supply that is more dependable and a water system that is easier to operate. When an entire community is dependent on one or a few sources, the quality of the water is important to the health and well being of each community member. The quality of a community water supply must be good; a failure in a public supply will affect more people than failure in individual family supplies. Depending on the type of contamination, simple community treatment systems may be able to ensure adequate water quality.

2.3 Simple Treatments for Community Systems

Community water treatment systems should be used under the following conditions:

- When a water source serves a larger population than can be served by household or individual treatment systems, especially in rural villages and towns
- When a community water source is contaminated and simple protective measures can neither improve water quality nor stop the contamination
- When resources in the community are adequate to cover the cost of construction, operation, and maintenance

The best method of water treatment removes the contamination, can be built with local materials at a low cost, uses few mechanical parts, requires little use of chemicals, and is easy to operate and maintain. Slow sand filters meet these criteria.

Slow sand filters, as described in Section 3, are excellent choices for treating community supplies, especially for gravity flow systems with pond or river sources. If the people dedicated to the maintenance of the slow sand filter are not available, an alternative method must be found. Slow sand filters require frequent, though simple, maintenance.

The water treatment procedures described within this manual are for treating water sources with generally good raw water quality. Treatment choices that are described within this section are not to remediate or restore water quality sources. Water treatments for heavily contaminated water supplies are beyond the scope of this text. Raw water quality analyses should be reviewed by individuals with special training or expertise in the field of water quality and health standards. The Water Supply Management Program of the U.S. Army Center for Health Promotion and Preventive Medicine (USACHPPM), located at Aberdeen Proving Ground in Maryland, can assist various military elements worldwide with drinking water issues. Planners should contact USACHPPM during the initial planning and reconnaissance for guidance on testing requirements and sampling. The appropriate host nation agencies and Ministry of Health should sample and analyze the water.

General drinking water quality guidelines issued in 1996 and amended in 1998 by the WHO are recommended for use by populations in developing countries, if practicable. Due to the technological requirements for some contaminate removals, meeting all the requirements of the WHO or the Host Nation Standards may not be possible. Long-term health effects such as cancer and nervous system damage may be caused by concentrations of arsenic and/or chromium that exceed the recommended standards. The acute health affects of contaminated water are generally very well understood and are addressed worldwide. Examples of acute effects caused by unsafe drinking water are polio, typhoid, diarrhea, diphtheria, and amoebic dysentery. Other problems caused by contaminated water or by lack of sufficient clean water are illustrated in Table 2 - 1.

2.4 Advanced Treatment for Community Systems

Advanced treatment processes for community water supplies are those that require highly skilled construction and operation, and are usually very expensive. Rarely are such systems appropriate for rural water supply systems, but several are briefly described here.

- **Conditioning.** Conditioning is the elimination of minerals and other substances that give water a bad color, taste or odor. Conditioning water supplies is less important than disinfection, but pleasant water encourages people to use the safe source.

- **Aeration.** Aeration is a conditioning process that exposes water to oxygen in the air. It changes iron and manganese in water to solid particles, so they can be removed. Aeration will also remove gases, bad tastes, and odors. Many methods of aeration can be used on small water supplies, but an expert's advice is recommended. All methods require energy to expose the water to air.

- **Desalination.** Desalination is the process of removing salt from a water supply. It is a highly technical and very expensive process. Solar distillation is the simplest method of desalination, but it is rarely appropriate for small water supplies. Choosing a salt-free water source is recommended.

- **Clarification.** Coagulation and flocculation are part of the clarification process that speeds sedimentation. They prepare water for filtration and can reduce bacteria levels. An alum solution added to turbid water causes suspended matter to form larger particles that settle quickly. Coagulation and flocculation are often used in treatment systems for large towns and cities. These processes are typically followed by rapid sand filtration. A rapid sand filter is a tank containing sand in selected sizes. It is used for clarification of turbid water. Water is forced quickly through the sand bed. A *schmutzdecke* has no time to develop in a rapid sand filter as it is backwashed often. A pump is necessary to backwash the filter. Construction and operation costs are high because the system of valves, pumps, and dosing devices require skilled operation and laboratory control. Regular maintenance is required.

- **Disinfection.** Mechanized disinfection technologies include chlorinator units that are used to feed a chlorine solution into a pumped water supply. Several different types of mechanized units are available which feed the chlorine in liquid or tablet form. Mechanized units require a power source, sophisticated maintenance, and laboratory control.

- **Water Treatment Plants.** Small, prefabricated, packaged water treatment plants may be an economically viable alternative for some small communities. These treatment plants are highly mechanized systems, which combine several different processes to clarify, condition, and disinfect large volumes of water. A treatment plant requires a reliable source of energy, skilled construction, operation and maintenance personnel, and constant supplies of chemicals; they are expensive to buy, to operate and to maintain. Treatment plants are rarely appropriate to small rural water supply systems, although they can sometimes be used at hospitals, schools, or other locations where trained operating personnel are available.

2.5 Sources of Drinking Water Supplies

The selected water sources dictate raw water quality, adequacy, and reliability. The raw water quality determines the required treatment. Groundwater is the preferred choice for water supply development. Groundwater generally does not require extensive treatment (if any), and operations of the system can be minimal, possibly limited to pumping and disinfection. If there is insufficient water available to meet the existing needs of a village, school, or other population, the first choice for additional water supply is groundwater. If groundwater is not available or is too expensive to obtain or requires extensive treatment, other water sources must be investigated.

When a suitable aquifer does not exist, relatively clear water from lakes and streams is generally the next best choice. River waters can be heavily silted. Pretreatment, such as plain sedimentation or roughing filters, may be required prior to slow sand filtration. Sources that require chemical coagulation, rapid filtration, and disinfection should be selected only as a last resort. Mountain streams that lack significant upland development or agricultural use often can provide suitable water. Streams observed and reported to be relatively clear and free of significant sediment would be a recommended source for investigation for water supply development. Tests for water quality should be performed at the upper reaches of a stream where an impoundment would most likely be recommended. Table 2 - 2 provides a starting point for source selection.

Table 2 - 2 Preliminary Criteria for Drinking Water Supply Sources

Test Parameter	Excellent Source	Good Source	Poor Source	Rejectable Source
Average Biological Oxygen Demand (BOD_5), milligrams per liter (mg/L)	0.75 - 1.5	1.5 -2.5	2.5 - 4	>4
Average coliform, Most Probable Number (MPN) per 100 milliliters (mL)	50 - 100	100 - 5000	5000 - 20,000	>20,000
potential of Hydrogen (pH)	6 -8.5	5 - 6	3.8 - 5	<3.8
Chloride, mg/L	<50	50 - 250	250 - 600	>600
Fluoride, mg/L	<1.5	1.5 - 3	>3	N/A

Generally the bacteriological quality of a source for drinking water would require that the indicator bacterium *E. coli* not be detected in any 100 mL sample. However, it is recognized that in developing countries, the great majority of rural water supplies may have fecal contamination. In cases where the *E. coli* contamination exceeds the drinking water guideline values for the host nation, but the water supply must be used for the source, the host nation agency for drinking water regulation, should set medium-term targets for the progressive improvement of the water supply. The higher the population, the better the water quality should be, because the possible extent of a water-borne epidemic increases with higher population densities.

2.6 Analyzing a Water Sample

A water supply for domestic use should be free of disease-causing organisms and substances, which make the water unacceptable to its users. Several methods can be used to determine if a water supply is safe to drink. One method is analysis; an analysis measures the type and level of contaminants present in a sample of the water supply. The results of water analysis can verify the findings of a sanitary survey and suggest the level of treatment for a water supply.

The source of the water should also be carefully considered when assessing which potential contaminants will be present currently and in the future. Surface water may contain a variety of parasites as well as bacteria and viruses. Parasites must be removed. They may not be readily killed or inactivated by disinfection processes using chlorine. Water may test negative for coliform bacteria but still contain parasites. Shallow wells and seriously contaminated deep wells may exhibit similar pathogen hazards to surface water. Deep wells are subject to higher iron and manganese levels, may develop persistent bacteria fouling, usually harder and may contain high levels of fluoride and nitrate. The characteristics of the source water can also be expected to change for the worse. Water treatment recommendations should consider the probable future water quality of the source water.

It is highly recommended that a series of water samples are collected and analyzed before a water treatment system is designed for a particular well or surface water source. It is also highly recommended that the appropriate host nation authorities are involved or perform the analysis. Examples of appropriate host nation authorities are local, regional and/or national water supply authority, and the local, regional and/or national Ministry of Health. Other authorities may exist, depending upon the country.

There are five kinds of water quality analysis. All of them measure different characteristics of a water sample. The two most important types of analysis for small community water supplies are: 1) bacteriological tests and 2) physical and chemical tests. Bacteriological analysis identifies organisms associated with disease. Physical and chemical analysis identifies elements on a sample that make water turbid, offensive, or poisonous to users. Physical, chemical, and bacteriological analyses are important, but of these, bacteriological analysis may be the most important. Bacteriological contamination is more likely to occur in small community water supplies due to inadequate protection from human and animal activities. In addition, it is more likely to be associated with acute or quick symptoms of illness than those created by physical or chemical contamination.

A physical and chemical analysis includes tests for turbidity, color, taste, and odor, followed by tests for excess minerals, toxins, and elements, which may harm the system. Physical and chemical analysis is extensive and is best carried out in a well-equipped laboratory due to the complexity of the testing. Field kits are available for partial physical and chemical analysis. They require specially prepared materials and equipment. These kits can be costly and therefore usually impractical for analyzing water in isolated rural areas. Physical and chemical analysis requires skill, training, and experience. An expert should be consulted for details and assistance in conducting this kind of analysis. This section will generally describe bacteriological analyses of drinking water.

The most serious water pollution is bacteriological contamination, which can cause disease. Bacteriological analysis of a water sample finds and counts organisms whose presence indicated that disease-causing pollution has occurred in the water supply. These “indicator” organisms are members of a large group of bacteria called “coliform bacteria.” Most coliform bacteria do not cause disease themselves. However, they can enter water supplies from the excreta of humans and animals, which indicates the possible presence of pathogens, the disease-causing organisms in excreta. Coliform bacteria are quicker and easier to identify than most pathogens, so coliform levels are used to determine the bacteriological quality of water.

If the potential water source is surface water, sampling for bacteriological analysis should be conducted, preferably by the host nation, during the reconnaissance and planning effort. Most laboratories can perform this analysis, and the results only take a few days. By testing during the reconnaissance phase, valuable time can be saved in locating a viable water source. If the results from the analysis indicate that heavy contamination is present, another source should be sought. If possible, the cause of the contamination should be investigated and a determination made whether it is possible to stop the contamination at its source.

Bacterial testing methods are described herein to allow the reader to develop a more comprehensive understanding of the complete quest for pure water. The better we understand the work of others, the greater our appreciation will be in the development of drinking water projects. In the final analysis, the quality of the obtainable drinking water is determined by the collective efforts of all parties and individuals involved. This information can offer insight into the individual responsibilities and the importance of each activity, such as planning, reconnaissance, testing, design, construction, or operation and maintenance.

2.6.1 Testing for Bacteria

As previously stated, the host nation should be closely involved in the water analysis. This is particularly true for microbiological tests, due to the short holding time restrictions between sampling and running the tests.

The simplest and cheapest bacteriological water analysis procedure is the Standard Plate Count (SPC). It is a method of measuring the overall bacterial content in a water sample. In the SPC, small quantities of a properly collected water sample are mixed with a growth medium in a petri dish and incubated. A portion of all the bacteria types present in the water will develop into colonies. Although the SPC does not distinguish coliform from other forms of bacteria, it is a valuable procedure for evaluating the general bacteriological quality of a water supply. It is a good method for measuring basic bacteriological content when no other means of analysis is available. If time and funds allow, three sampling events spaced four months apart is recommended.

The equipment and supplies needed for the SPC are common to most laboratories. One milliliter of a diluted water sample is put into a sterile petri dish using a sterile pipette. Approximately 10 to 15 mL of sterile growth media, such as glucose agar, is poured over the sample in the dish. The sample and the agar are thoroughly mixed and incubated at 35 degrees Celsius (°C) plus or minus (+/-) 0.5 °C for 24 hours +/- 2 hours. The bacteria colonies are counted after incubation using an illuminated colony counter or a reading glass. If less than 500 colonies of bacteria grow, the water is considered relatively good. Most established laboratories would be familiar with the SPC.

Examining a water sample specifically for the presence of coliform bacteria is called "coliform detection." A "total coliform detection" will identify many sorts of coliform bacteria in a water sample. The presence of the particular fecal coliform bacteria known as *E. coli* is strong evidence of the presence of pathogenic organisms. Water that is free of coliform, or has a very low coliform count in a total coliform detection analysis, is considered free of disease-producing bacteria. Total coliform detection is the most frequently used bacteriological analysis.

Almost all rural water supplies detect coliform bacteria. Not all water supplies can be condemned. The level of coliform content in water tested, not simply the presence or absence of coliform bacteria, determines the safety of a drinking supply. The WHO International Standards for the bacteriological quality of drinking water vary depending on whether the water supply is unimproved, disinfected, or piped. Much higher standards are expected for improved supplies. Ideally, no *E. coli* are acceptable in any drinking water sample, and only low levels of other coliform bacteria are tolerated in unimproved supplies. The basic WHO standards are explained in Section 2.8 "Interpreting Results of Coliform Bacteria Detection."

Water quality testing and procedures should be conducted using the host nation's assets and resources. Water analysis can be conducted in a laboratory or in the field using special kits. Laboratories provide a controlled environment for analysis and often have extensive facilities for testing. Field kits decrease the problems of storing and transporting samples and are convenient, but field kit equipment is not always as complete as a laboratory. Lack of laboratory facilities is one of the greatest difficulties of conducting bacteriological examinations of water in remote areas. Analysis should begin as soon as possible after samples are collected to minimize changes in the bacteriological character of the water. Analysis can be performed properly in a laboratory when testing can begin within 6 hours. Field kits start the analysis procedure on the collection site, so they are highly recommended for circumstances where the delay between collection and laboratory analysis will be over 6 hours. Samples must be properly stored and transported to the nearest testing facility when neither laboratory or field analysis can begin within 6 hours. Some field kits are designed to hold samples under proper conditions until they arrive at a laboratory for analysis. Others contain complete portable analysis facilities.

2.6.2 Testing for Coliform Bacteria

Two basic methods are used to analyze for coliform bacteria. The first method is the multiple tube method, in which small measured volumes of sample water are added to a nutrient broth in one or more sets of five test tubes. The sample tubes are incubated, and the nutrient broth supports the multiplication of the bacteria. After 48 hours in incubation, the most probable number (MPN) of bacteria in the water sample is estimated based on the number of tubes that produce gas, the sign of bacterial growth. Field kits are available for the multiple tube method, but this test is most effectively performed in a well-equipped laboratory.

In the second method, the “membrane filter technique,” a measured volume of sample water is drawn or pushed through a flat filter that retains any bacteria present in the water. The filter is then placed on a growth medium and incubated. The bacteria multiply, forming visible colonies. The colonies are counted directly by eye or with the aid of a binocular-wide field microscope.

The accuracy of both methods of coliform detection is highly dependent on a water sample that is properly collected from the water source being evaluated. As part of the planning and reconnaissance phase, the reader should contact USACHPPM for preliminary and follow-on instruction regarding sampling and testing methods. More detailed information of these two methods is provided in the following two sections.

2.6.3 Multiple Tube Method of Coliform Bacteria Detection

In the multiple tube method, the number of coliform bacteria in a water sample is calculated based on a statistical estimate of bacteria growing in a set of five test tubes containing a mixture of nutrient broth and water sample. Any coliform bacteria present will ferment lactose in the form of gas when this mixture is incubated. Formation of a gas bubble in the test tube indicates the presence of coliform bacteria. An inverted vial is laced in the test tube to trap any gas bubbles that form. See Figure 2 - 1.

The three different types of multiple tube tests are the Presumptive Test, the Confirmed Test, and the Complete Test. The Presumptive Test is for general coliform bacteria detection. The Confirmed Test is a more thorough method than the Presumptive Test, and the Complete Test is the most accurate. However, the Confirmed and Complete Tests require more supplies, skills and experience to perform. The Presumptive Test is sufficient for testing most rural water supplies.

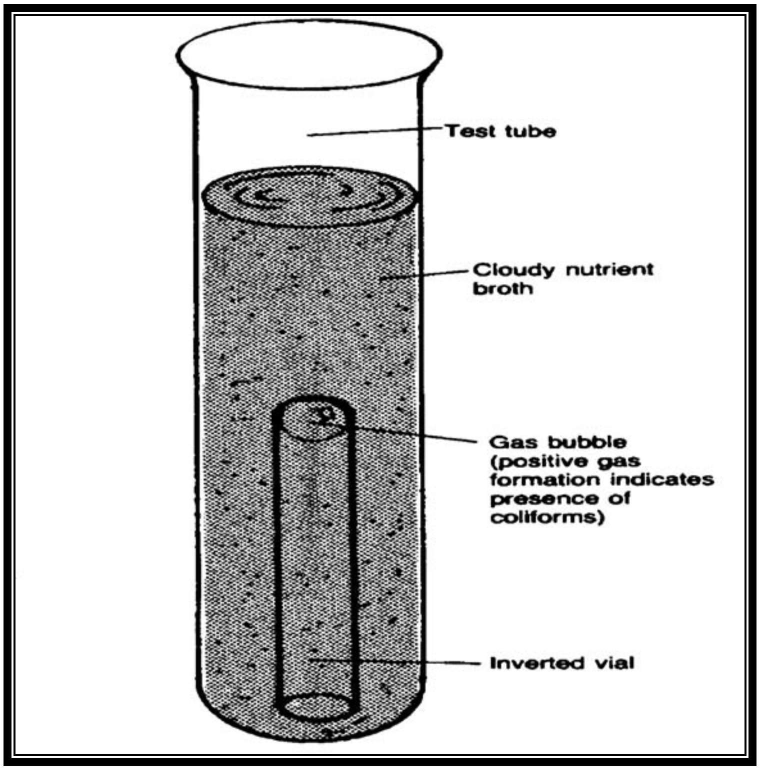


Figure 2 - 1 Multiple Tube Method of Coliform Bacteria Detection

In the Presumptive Test, five test tubes, filled with a mixture of nutrient broth and water sample, are incubated at 35 °C +/- 0.5 °C for 24 hours +/- 2 hours. If gas bubbles have formed in the nutrient broth surrounding the vial and if there is a small gas bubble in the inverted vial after this period of time, the test is considered positive. A positive test indicates coliform bacteria are probably present in the water supply. If no gas has formed, the test tubes are incubated for another 24 hours. If gas bubbles form during the second incubation period, the test is also considered positive. Absence of gas at the end of the second incubation period constitutes a negative test; meaning coliform bacteria are definitely not present. Refer to Figure 2 - 2.

A Confirmed or Complete Test can be performed on the same water samples following a positive Presumptive Test. However, the MPN of coliform bacteria per 100 mL of water can be estimated after a positive Presumptive Test using a standard MPN table. See Table 2 - 3. It is important to remember that MPN values are not absolute numbers of coliform bacteria present but are used as estimates for judging water quality.

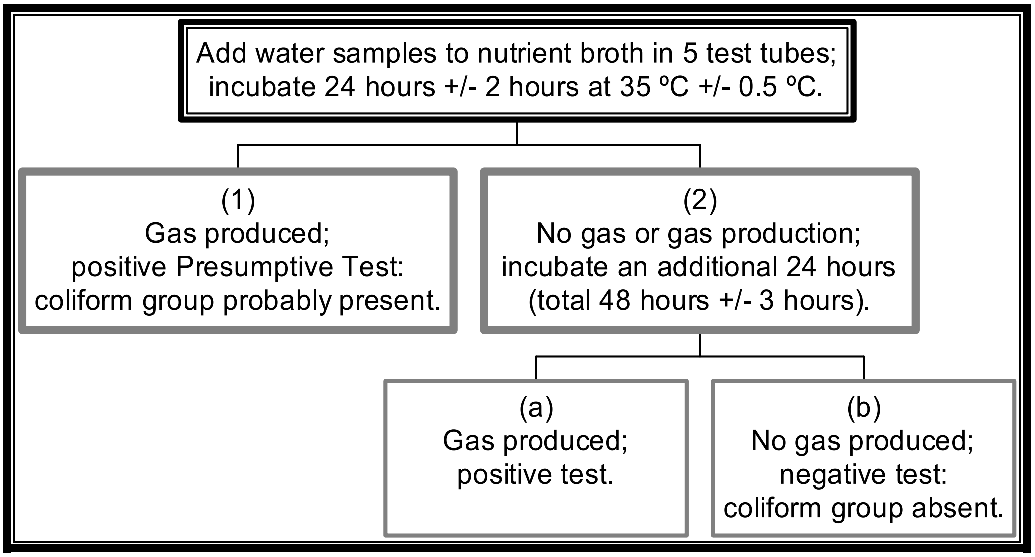


Figure 2 - 2 Multiple Tube Method of Coliform Bacteria Detection, Presumptive Test

Table 2 - 3 Most Probable Number Index for Coliform Bacteria

Number of tubes giving positive reaction	MPN of Coliform bacteria per 100 mL of water
0	<2.2
1	2.2
2	5.1
3	9.2
4	16.0
5	>16.0

Note: when five 10-mL portions are used

2.6.4 Membrane Filter Technique of Coliform Bacteria Detection

In the membrane filter method, a vacuum draws a water sample through a funnel and filter. The wet filter is then removed from the filter holder and placed in a petri dish over a pad saturated with a growth medium. See Figure 2 - 3. The petri dish is placed in an incubator. Any coliform bacteria present will grow in distinctly colored colonies. The filter is examined with the naked eye or under a microscope and the colonies are counted.

Membrane filters must be examined within 30 minutes of their removal from the incubator so that the difference between the colored colonies is easier to see. The colors will stabilize after the filters dry, and results can be preserved for future reference by storing the filter between two layers of plastic film.

Field kits for the membrane filter test are available as units from several manufacturers. Consult USACHPPM or the regional or national water authority for information on acquiring kits. If one brand of equipment is already being used by an agency, additional equipment should be from the same manufacturer to assure compatibility. Parts of field kits are usually not interchangeable. Be sure a complete instruction manual is included with the kit.

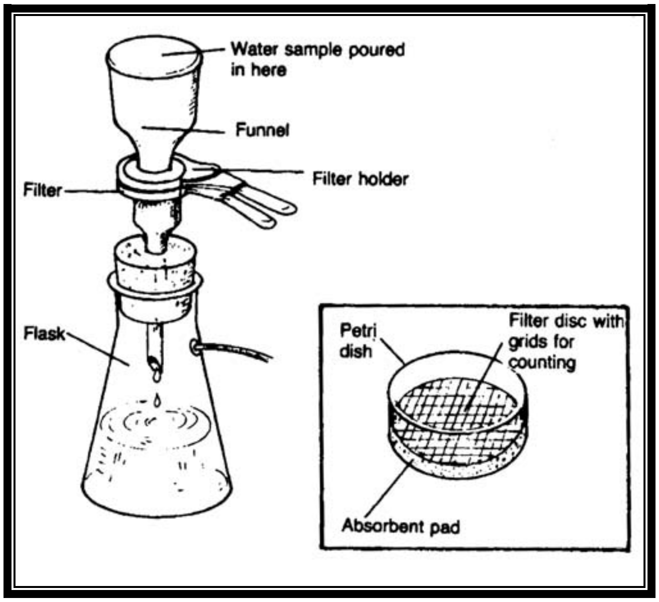


Figure 2 - 3 Membrane Filter Method of Coliform Bacteria Detection

Facilities for incubation are the main constraint for coliform bacteria detection. Temperatures must be controlled very carefully. It is not always possible to maintain the exact temperature ranges in an incubator under field conditions unless portable incubators are used. Portable incubators are relatively expensive and require a power source such as a car battery for operation. If incubation with accurate temperature control is not possible on site, the filter must be transported to an incubator immediately. If no incubator is available at all, the human body can provide the incubation temperature for the total coliform test. Vests with pockets for membrane filter plates can be made or purchased.

2.6.5 Comparison of the Multiple Tube and Membrane Filter Methods

The advantages of the multiple tube method over the membrane filter method are as follows:

a) The equipment and supplies necessary for the multiple tube test are common to well-equipped laboratories. They are more readily available in most countries than equipment and supplies for the membrane filter method. Membrane filter portable kits must be imported from the manufacturer, which involves high expenditure of foreign exchange for acquisition and replacement parts. Because costs are high, availability and distribution may also be problems.

b) The equipment for the multiple tube method can be re-used. The membrane filter portable kits are disposable and cannot be used more than once.

c) The multiple tube method of bacteriological analysis is appropriate for established laboratories near the water supply to be tested but not for isolated rural areas without reliable laboratory service.

Advantages of the membrane filter method over the multiple tube method for field analysis are as follows:

a) The number of coliform bacteria colonies grown in a filter can be visually identified and counted. The multiple tube method estimates the number of coliform bacteria statistically.

The membrane filter results can be preserved for future reference unlike the multiple tube results.

b) The membrane filter method requires less equipment preparation and clean up. Disposable equipment and pre-prepared supplies are standard parts of membrane filter field kits. The membrane filter test also takes less time to perform than the multiple tube method. The membrane filter method requires 24 hours from sample collection to interpretation of results. The multiple tube method requires 48 hours for incubation alone, and can take up to 96 hours for complete procedures. Therefore, where labor costs are high or time onsite may be limited, the membrane filter method may be less expensive to use.

c) The membrane filter technique is better adapted to fieldwork and emergencies than the multiple tube method. Preparation for, performance of, and clean up after the membrane filter test are less complicated and quicker than for the multiple tube method. Membrane filter test equipment and supplies take up less space than those for multiple tube tests. More equipment especially adapted for field conditions is available for the membrane filter tests than for the multiple tube tests.

The membrane filter method is appropriate when reliable laboratory service is not available within six hours of water sample collection and when the kits are available and not too expensive.

2.7 Interpreting Results of Coliform Bacteria Detection

Ideally, all samples should be completely free of coliform bacteria. It is not always possible to attain such a high standard in rural areas. Local standards should be used if they exist. As discussed earlier, USACHPPM should be contacted in the planning and reconnaissance phase, but the WHO recommends the following standards:

- Throughout any year, 95% of the drinking water samples should not contain any coliform organisms in 100 mL of water.
- No sample should contain E. coli in 100 mL of water.
- No sample should contain more than 10 coliform organisms of other types per 100 mL.
- Coliform organisms should not be detectable in any two consecutive samples of 100 mL of water.

2.7.1 Frequency of Testing

After consulting with USACHPPM and if the supply does not meet these standards or other more specific local standards, the water source should be considered unsuitable for use without treatment in the microbiological (bacterial) evaluation. If any coliform organisms are found, further investigation is needed to determine their source. The first step is immediate re-sampling and analysis. If subsequent water samples do not meet the standards summarized in Section 2.7, then superchlorination of the well is recommended. Resampling should be conducted after superchlorination. If subsequent samples still do not meet the proper standards, then a water treatment system may be necessary to improve the water quality. Disinfected water supplies should be completely free of any coliform bacteria regardless of how polluted or contaminated the raw water may have been.

If possible, during the planning and reconnaissance period, water sample collection and analysis should be repeated under varying conditions. A number of samples should be collected over a period of days for each analysis period. Reliance cannot be placed on the results of analysis of a single sample from a water supply.

If time and funds allow, three sampling events spaced four months apart is recommended. The sampling events should be accomplished by the host nation and should occur after the exercise is completed.

2.7.2 Summary

When an analysis is completed, results need to be carefully interpreted in conjunction with the observations of a sanitary survey. An analysis determines the type and level of contamination present in a sample of a water supply. A sanitary survey identifies the probable sources of that contamination. Drilling a water well often contaminates the water. However, this can be remediated by superchlorination and should not be considered permanent. Conclusions from both processes need to be balanced to judge the safety of existing water systems and plan appropriate water quality improvements. An example of a typical field form for recording information for later use and consulting is indicated by Worksheet A, Appendix C.

SECTION 3

SEDIMENTATION BASINS AND SLOW SAND FILTRATION

EXECUTIVE SUMMARY

The primary goal of this section is to develop a basic level of knowledge about slow sand filtration and associated drinking water treatment processes. This knowledge can then be used to provide better support to field activities to produce successful water supply and treatment projects. Success can be measured by more efficient planning, better construction techniques, and ultimately through a quality finished drinking water product.

Depending on the amount of water to be treated, commercial water treatment equipment using this same technology is available for purchase and installation. If adequate funds are available and due to the time constraints of an HCA exercise, it is generally recommended that commercial equipment be considered for installation. Design and construction of hydraulic structures requires careful attention to reactive forces and concrete quality; this can be accomplished onsite but requires several weeks to ensure quality.

3.1 Introduction

Before slow sand filtration is recommended for treatment of specific source water, the following questions must be answered:

- Can this technology produce safe and palatable finished water from the specific source water?
- Will the filtration cycle length (the time period between filter scrapings) be acceptable? What is a tolerable cycle length? Most successful treatment plants today have cycle lengths of 1.5 to 2 months or longer.
- Is it possible to use local materials as filtration media?
- Is adequate construction funding available to meet minimum necessary filter sizing for the associated population?
- What training level is required to install/operate/maintain the treatment system?
- Do compact or packaged commercial systems exist for the flow rates and quantities that need to be supplied?
- Is adequate space available?

A review of the technology of slow sand filtration and its performance will provide insight into whether or not this is a viable alternative.

For developing countries, the selected treatment system must be able to operate under very adverse economic, social, and environmental conditions. These adverse conditions include the following:

- Lack of sufficient funds to build high-cost treatment systems;
- Very low budgets for operation and maintenance;
- Water-system personnel that are not trained in the operation of sophisticated treatment systems;
- Remote locations which make it difficult to obtain spare parts and treatment supplies; and
- Harsh semi-tropical environments that tend to corrode or disintegrate metal parts.

A water treatment system is needed that not only reduces the levels of harmful disease causing organisms, but can also remain operational under these adverse conditions. The treatment system must be effective, economical to build, and simple to operate and maintain. Generally, the use of locally available materials in the treatment system is especially important because of the typical isolation of the villages and lack of economic foundations to pay for high priced treatment systems.

Under these considerations, the process for “slow sand filtration” is likely to be the most suitable treatment process for groundwater or impounded surface water. General maintenance for these systems includes manual cleaning by removing the dirty top sand rather than backwashing. The sand is not stratified and the hydraulic characteristics are a function of the finer portions of the sand.

The advantages of the slow sand filter are the following:

- Removes 90% to 95% of bacteria responsible for water-related disease;
- Removes practically all water borne parasites;
- Removes suspended matter and reduces color;
- Can generally be built with local materials using local skills and labor;
- Needs no complex mechanical or electrical machinery; and
- Requires only simple operation and maintenance.

Sand filters are not the best choice in all situations. Under certain conditions a slow sand filter is not very effective. If a source is highly turbid, slow sand filtration is not the best treatment method. Very turbid water clogs the filter in a few weeks and makes the system require frequent maintenance. In some cases, additional treatment for highly turbid source water may be required, such as sedimentation basins or roughing filters. Where the source water has high turbidity, it is good policy to place a “sedimentation basin” or “roughing filter” as a predecessor to the slow sand unit. This recommendation is for almost any surface water or groundwater source that is relatively high in iron (1 mg/L or more). These units would extend the slow sand filter run time by removing a portion of the solid particles which would clog or “blind” the filter sooner. If large quantities of clean, suitably sized sand are not available or cannot be obtained easily, the slow sand filter is not a good alternative. If land is in short supply, a slow sand filter is not the best choice since it requires large areas of land.

Slow sand filtration effectively removes organic matter, pathogenic organisms, color and mild turbidity to provide clean and safe water. No other single treatment process can improve the physical and biological quality of water as well as sand filtration. Slow sand filters offer other advantages that make them useful in rural areas. They can be constructed with local materials and labor at a low cost. Operation and maintenance requirements are few and local labor can be trained to perform the required duties.

Even though sand filters are not difficult to design and operate, special care must be taken to ensure their efficient operation. This section will describe the basic design features.

Many of the disadvantages of traditional slow sand filtration mentioned above have been overcome in packaged commercial systems such as those described in Appendix D.

3.2 Treatment Chain

The scope of this manual covers only three aspects of water treatment: disinfection, filtration, and sedimentation. This combination of low cost and simple technologies will provide adequate treatment for many water supplies. It cannot treat all contaminants or problems that may be discovered. However, it provides a reasonable degree of safety for most rural communities in developing countries when proper design, construction, operation and maintenance practices are provided. Chlorination is the only type of disinfection discussed within this handbook. If operated properly, it will offer significant protection to rural water supplies when performed in conjunction with proper source water protection measures and good sanitation practices within the community.

3.3 Disinfection

Disinfection involves destruction or inactivation of microorganisms, which are the primary public health concern in the treatment of drinking water. The finished treated water storage must be maintained with a disinfection residual in the storage tank to ensure proper disinfection. Because the health of water consumers should be of principal concern to those responsible for supplying water, design and construction of facilities for disinfection must be carefully executed. The application of chlorine to water is the preferred method of disinfecting water supplies.

Terms frequently used in connection with chlorination practice are defined as follows:

- **Chlorine demand** - the difference between the concentration of chlorine added to the water and the concentration of chlorine remaining at the end of a specified contact period. Chlorine demand varies with the concentration of chlorine applied, time of contact, temperature, and water quality (particularly the concentration of suspended solids and dissolved organic carbon).

- **Chlorine residual** - the total concentration of chlorine remaining in the water at the end of a specified contact period.

- **Combined available residual chlorine** - any chlorine in water that has combined with nitrogen. The most common source of nitrogen is ammonia, and compounds formed by the reactions between chlorine and ammonia are known as chloramines. The disinfecting power of combined available chlorine is about 25 to 100 times less than that of free available chlorine, but chloramines are less apt to form objectionable disinfection by-products.

- **Free available residual chlorine** - that part of the chlorine residual that has not combined with nitrogen.

Chlorination is typically the last treatment provided prior to sending water to storage. The process of chlorination offers a “first line defense” against disease in populated areas and should always be given major consideration. If there is any chance of parasite contamination, chlorination may not be adequate and treatment processes to remove parasite may be required. Often, for HCA exercises, chlorination is the only treatment necessary.

See Appendix E for disinfection procedures and Section 4 for designing small disinfection units.

3.4 Filtration Process

Filtration, in the sense that it is used here, refers to the physical, chemical, and biological treatment offered by natural mechanisms through the construction of a slow sand filter. It is not the first process that may be utilized in a treatment scheme, but it is the most likely process that will be used for a rural water supply in a developing country should treatment be required. Slow sand filters have a distinguishing feature that rapid sand type filters do not. Slow sand filters have the presence of a thin layer, the *schmutzdecke*, which is a large variety of biologically active microorganisms that forms on the surface of the sand bed. A slow sand filter is comprised of fine sand, approximately 1.2 m thick, supported on two or three gravel layers. It is a very simple and effective technique for purifying surface water. It will remove significant turbidity from the water as well as most of the pathogens without the addition of chemicals. Slow sand filters can frequently be constructed largely from locally available materials.

The walls of the filter can be constructed of concrete or stone. Sloping walls dug into the earth, supported or protected by chicken wire reinforcement, and lined with sand or a sand-bitumen mixture could be a cost-effective alternative to concrete. Inlets and outlets should be provided with controllers to keep the raw water level and the filtration rate constant. Bottom drains consist of a system of manifolds and lateral pipes as shown in Figure 3 - 1. The filtration rate usually employed in developing countries is between 2.5 to 6.0 cubic meters per square meter per day (m^3/m^2/day). Higher rates may be used, but should be tested to ensure that the higher rates yield good quality water. The system should be designed for flexibility. Highly turbid water may need some form of pre-treatment such as settling or rough filtration.

Modern, commercially available packaged systems such as the intermittently operated slow sand filter technology described in Appendix D overcome many of the disadvantages of traditionally designed slow sand filter shown in Figure 3 - 1. However, project costs and budgets must be considered before selection of the appropriate technologies and method of construction.

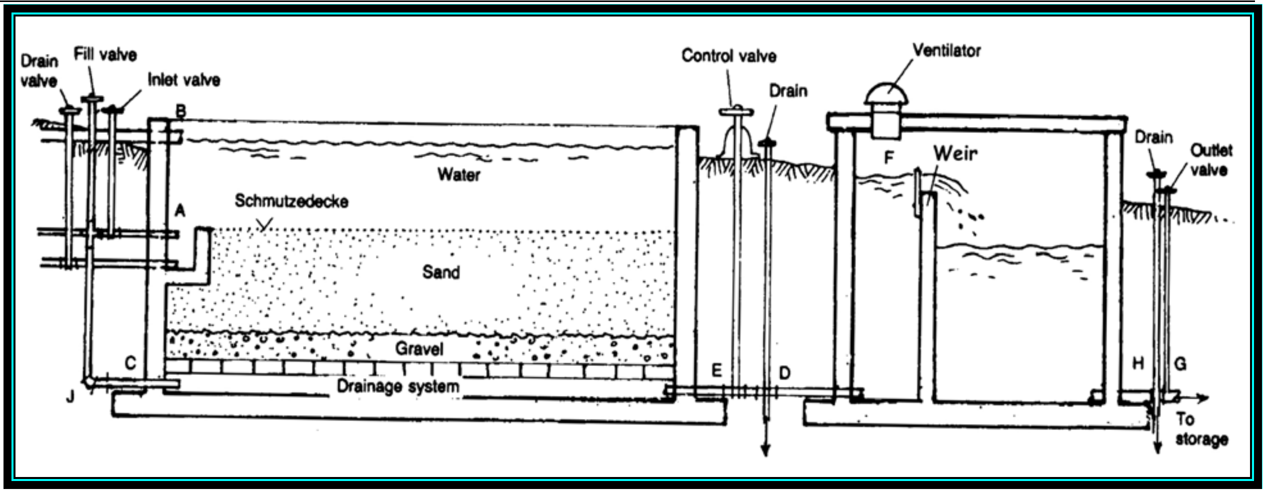


Figure 3 - 1 Slow Sand Filter with Valve System and Clear Water Well

3.5 Sedimentation and Roughing Filter Basins

Sedimentation is the removal of suspended matter from water through a process of settling. In the process, particles heavier than water settle to the bottom of a specially designed tank. Roughing filters can be constructed very similar to sedimentation basins, except the inside of the basin is filled with a coarse gravel media. The fine solids crossing a rectangular sedimentation tank have to overcome a vertical settling distance of 1 to 3 m before coming into contact with the tank bottom. Due to small settling velocities, a large portion of the fine solids might not reach the tank bottom and hence, will not be separated. The same sedimentation tank can be filled with rough filter material 0.6 m deep and layered with gravel. The gravel size should range from 3.0 to 25.0 mm. The fine solid particles flowing through the filter are now touching the gravel surface already after a few millimeters of settling distance. Since the filter material drastically reduces the settling distance required for travel, roughing filtration is thus a more effective process for solids removal than plain sedimentation.

Sedimentation is a very important process. Particles which enter a water supply through erosion and run-off can be harmful to water distribution and treatment systems. Suspended particles can block pipes, clog filter screens and filter beds, reduce storage tank capacity and affect water quality since pathogens may be trapped in the particles. These particles must be removed or receive further treatment before water can be consumed. Further treatment may be needed to remove fine clay and colloidal matter which have a very slow settling rate and are difficult to remove by plain sedimentation. If turbidity exceeds 20 nephelometric turbidity units (ntu) for any time exceeding a few days, a roughing filter should be installed. Roughing filters can reduce turbidity from 50% to 80% and reduce the amount of maintenance on slow sand filters considerably.

Sedimentation basins are designed so that turbid water flows though them at a low velocity, and suspended particles settle out. For rural areas, rectangular masonry basins are the least expensive and simplest to install and the easiest to maintain. Tanks may also be made of reinforced concrete. Water that passes through a sedimentation basin loses suspended solids but generally must receive further treatment in a slow sand filter.

A sedimentation basin can be constructed locally. Various materials can be used in the construction process. For small to medium tanks, mass concrete or masonry is preferred. They require little skilled labor, and materials are generally available. Reinforced concrete is used for larger tanks. The use of reinforced concrete requires more skilled laborers than are needed for either masonry or mass concrete basins. Further, the cost of materials is much higher. See Worksheet B, Appendix C for formulas to calculate quantities needed for a concrete sedimentation basin.

3.6 Designing a Slow Sand Filter

After the planning process has been completed, the following three items must be given to the construction supervisor:

- A map of the area marked with the locations of the slow sand filter, other treatment units planned, location of the water source, and any important landmarks. See Figure 3 - 2. Whenever possible, the filter should be located close to the water source.

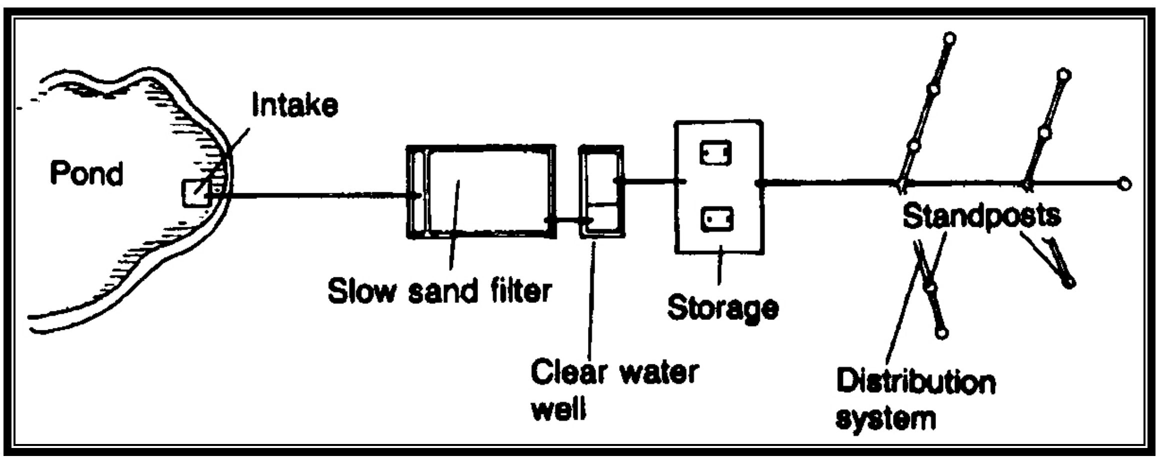


Figure 3 - 2 Location Map

- A list of all labor and materials needed for the project. A sample list appears in Table 3 - 1.
- A drawing indicating the elevation changes from one treatment process to the next throughout the whole treatment train.
- A plan of the slow sand filter showing the design dimensions as shown in Figure 3 - 3.

3.7 Design Information

Follow the directions in this technical note as a basic guide. The basic parts of a slow sand filter are the following:

- Water reservoir above the layer of filter sand
- Filter bed
- Filter bottom and water drainage system
- Filter box containing the three items above
- Filter control system

Table 3 - 1 Materials List for Slow Sand Filters

Item	Description	Quantity	Estimated Cost
Labor	Forman		
	Laborers		
Supplies	Bricks		
	Cement		
	Gravel, 60-100 mm		
	Sand, 0.15 – 0.35 mm		
	Gate Valves		
	Butterfly Valve		
	Polyvinyl Chloride (PVC) Pipes		
	Wooden Stakes		
	Rope		
	Pipe Glue		
Tools	Digging Tools		
	Small Saw		
	Sieves		
	Hammers		
	Nails		
	Measuring Tape		
	Trowels		
	Wheelbarrow		
	Mortar Box		

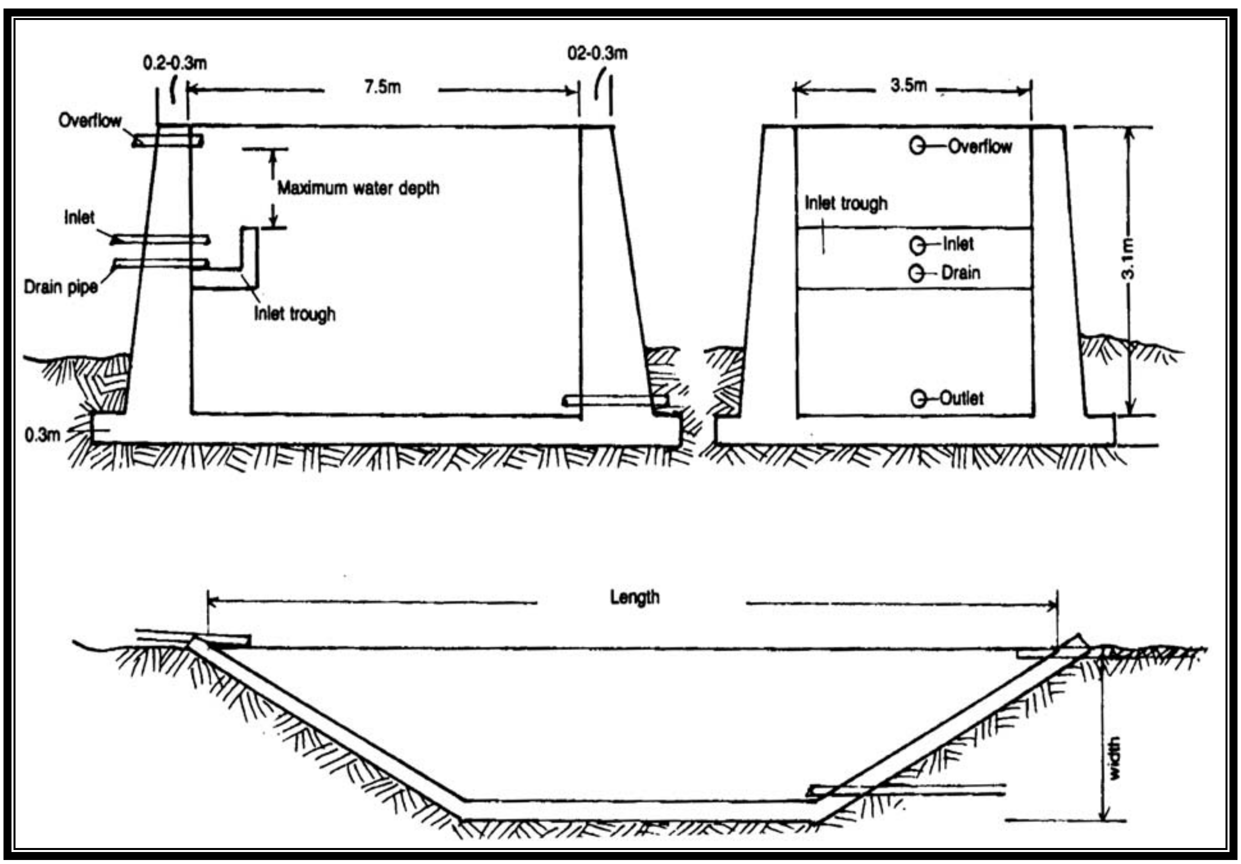


Figure 3 - 3 Design of a Slow Sand Filter

Each part serves an important function in the overall operation. Before beginning to design the filter, it is necessary to determine the following:

- The amount of water that must be provided to the community
- The capacity of the filter
- The number of filter beds desired

The slow sand filter should be designed to serve the community for about 7 to 10 years. Some systems can be designed for up to 20 years. The following three steps should be used for designing a slow sand filter.

Step 1: Determine Population Served

In designing for the capacity of a slow sand filter, make an estimate of the community's population 10 years in the future. Although accurate information on population growth may not be available, gather any available data from local sources and make an estimate.

Table 3 - 2 shows the population growth factors that can be used to estimate the future population of a community. For example, if the population of a certain town is 1,000 and the yearly growth rate is 2.5%, the population in 10 years can easily be determined in the following way. First look on Table 3 - 2 under the column 2.5%, and find the number in the row for a 10-year design period.

Table 3 - 2 Population Growth Factors

Design period (years)	Yearly Growth Rate (%)					
	1.5	2	2.5	3	3.5	4
7	1.1	1.17	1.19	1.23	1.27	1.32
10	1.16	1.22	1.28	1.34	1.43	1.48
15	1.25	1.35	1.45	1.56	1.65	1.80
20	1.35	1.45	1.64	1.82	1.99	2.19

The growth factor is 1.28. Multiply the present population (1,000) by 1.28 to determine the population in 10 years:

1,000 people x 1.28 = 1,280 people

Therefore, the sand filter should be designed for a population of 1,280 people.

Step 2: Determine Total Daily and Hourly Demand

For sizing the sand filter, calculate the daily water demand. When determining demand, assume a level of consumption of 40 liters per person per day (L/person/day). Hence, the total daily demand is determined by:

Q_d = 1,280 people x 40 L/person/day = 51,200 liters per day (L/day)

or

approximately 52 cubic meters per day (m^3/day).

The hourly water demand takes into consideration daily peak flows to ensure that water is provided to the users without interruption. Determine the hourly water demand by taking 20% of the daily demand. For example:

$$\mathbf{Q_{hr} = 52\ m^3/day \times 0.20 = 10.4\ cubic\ meters\ per\ hour\ (m^3/hr).}$$

Step 3: Determine The Required Total Filter Area

The filter bed area (**A_f**) can easily be calculated using the following formula:

$$A_f = \frac{Q_{hr}}{V}$$

Where **A_f** is the surface area of the filter in square meters (m^2), **Q_{hr}** is the hourly flow demand as determined earlier, and **V** is an allowable range of velocity for water flow through the filter bed. Velocity should range between 0.1 and 0.2 cubic meters per hour (m^3/hr). From the previous example, the hourly water demand (**Q_{hr}**) quantity of water is **10.4 m^3/hr**. If an allowable filtration rate (**V**) of **0.2 m/hr** is selected, the total filter area equation becomes:

$$\text{Area} = (10.4\ m^3/hr) / (0.2\ m/hr) = 52\ m^2$$

3.8 Number of Sand Filters Required

A minimum of two filters should be constructed. This allows one filter to be shut down for cleaning or maintenance while the other filter continues to treat water. Each should have a filtration rate of 0.1 m/hr when operating together. With one filter closed down, the filtration rate for the filter in operation would be no more than double the rate or 0.2 m/hr. From the above example, the required area of the filter beds is 52 m^2. Therefore, two filters with 26 m^2 each should be constructed (52 $m^2 \div 2 = 26\ m^2$). Space for a third filter with the same area should be reserved for future expansion.

Design the filters so that the ratio of length to width is between one and four. For example, each filter could have a width of 3.5 m and a length of 7.5 m (7.5 m ÷ 3.5 m = 2.1, which is between 1 and 4). The site selected impacts the dimensions selected for the filter and how each filter can best fit.

For filters with water loads of 6 m^3/hr or less, reinforced concrete pipe filters (otherwise known as ferrocement filters) can be constructed. These are especially useful in smaller communities. A pipe filter is easier and cheaper to build than a rectangular concrete or masonry filter. Pipe filters are built using chicken wire, wire strips, and a mixture of one part cement and two parts sand. The wire mesh is usually 20 mm thick and the walls are between 60 and 120 mm thick. See Figure 3 - 4 for more detail. Pipe filters should not be more than 5 m in diameter and should have a filtration rate that does not exceed 0.1 m/hr.

The greater the capacity needed, the greater the number of filter units that should be built. Filter units should not be too large in order to simplify cleaning.

To determine the number of filters needed for a system, use the following formula:

$$N = 1/4\sqrt{Q}$$

The formula is such that the number of filters is equal to one-fourth the square root of the infiltration flow rate. Where N is the number of filters required and should always be no less than 2. Q is the water flow rate in m^3/hr.

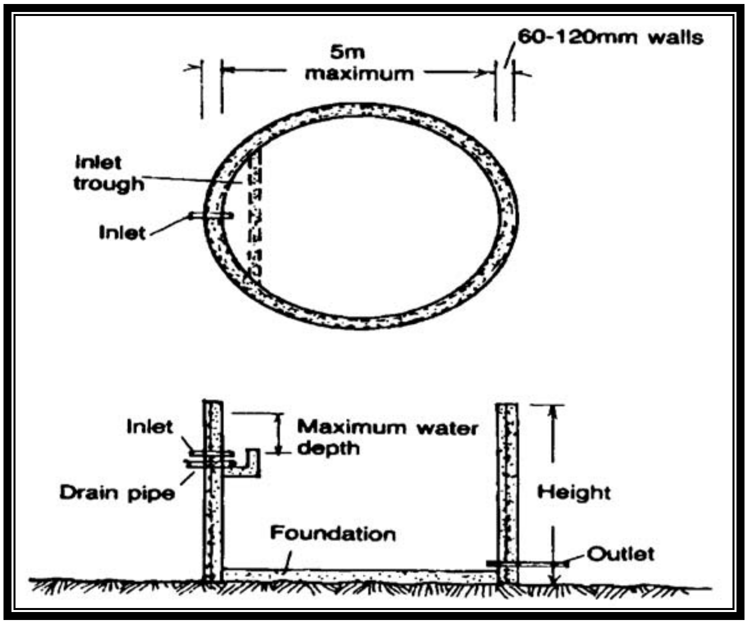


Figure 3 - 4 Ferrocement Sand Filter

In the example, the flow rate, Q, is equal to 10.4 m^3/hr. Hence,

$$N = \frac{1}{4}\sqrt{10.4} = \frac{1}{4} \times 3.2 = 0.8,$$

indicating that only one filter is required for treatment purposes. However, two filters should be constructed for operational and maintenance purposes.

3.9 Filter Boxes

The filter box consists of four parts:

- Water reservoir above the filter bed
- Filter bed
- Underdrain system
- Filter control system

The water reservoir above the sand level provides a waiting period for the water in which additional sedimentation can take place and produces a head of water greater than the resistance of the filter bed. A head between 1.0 m and 1.5 m above the filter bed is an acceptable water depth. The walls of the reservoir should extend 0.2 to 0.3 m above the water level as shown in Figure 3 - 5. This extension is called the "freeboard."

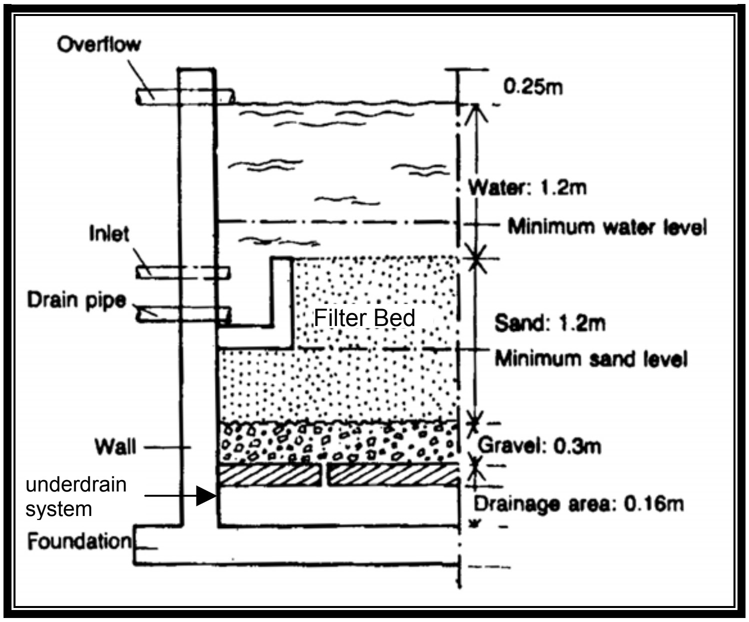


Figure 3 - 5 Filter Bed Construction

The filter bed is where the purification process takes place. The filter material is usually a fine-grained sand and should be free from clay loam and organic matter. The diameter of the sand should be just small enough to ensure that the filter produces good quality water and to prevent the entry of clogging material into the filter bed. Sand size is described by two measurements -- the effective size and the uniformity coefficient ($\mathbf{U_c}$). The effective size of the sand is the size of the sieve opening through which 10% of the filter bed material will pass. The effective size of the sand used in slow sand filters is about 0.2 mm, but it may range between 0.15 mm and 0.35 mm. The uniformity coefficient of the sand ($\mathbf{U_c}$) used in the filter should be between 1.5 and 3.0. The uniformity coefficient is the ratio between the sieve size through which 60% of the filter material passes (d_{60}) and the size through which 10% of the sand passes (d_{10}). The uniformity coefficient is determined as follows:

$$U_c = (d_{60}) \div (d_{10})$$

The formula simply states that the diameter through which 60% of the granular material passes is divided by the diameter through which 10% of the material passes. For example, if 60% of the material passes through a sieve of 0.61 mm and 10% through a sieve of 0.21 mm, the uniformity coefficient is calculated below:

$$U_c = (d_{60}) \div (d_{10}) = (0.61 \text{ mm}) \div (0.21 \text{ mm}) = 2.9.$$

The uniformity coefficient is between 1.5 and 3. Therefore, the granular material is acceptable for use.

Determining the effective size and the uniformity coefficient of sand requires a set of standard sieves and good scales, equipment which is common to soil laboratories. Other places that can perform sand analyses are public works departments, concrete mixing plants, and cement factories. Check with the local population to determine if sized sand can be obtained. Graded sand may be difficult to obtain locally. If sized sand is unavailable, choose coarser sands for the filter bed. Try to avoid using fine sands that are too fine, or $U_c \leq 3.0$.

Next, determine the amount of sand needed for the filter. To determine this amount, the volume occupied by the sand, V_s, must be calculated using the following formula:

$$V_s = (\text{area of filter bed, } A_f) \times (\text{thickness of filter bed})$$

Where the area of the filter bed is the following:

$$A_f = \text{length of filter} \times \text{width of filter}$$

From the example,

$$A_f = 3.5 \text{ m} \times 7.5 \text{ m} = 26.25 \text{ m}^2$$

Therefore, selecting a filter bed thickness of 1.2 m, the volume of material for each filter bed can be determined as follows:

$$V_s = (26.25 \text{ m}^2) \times (1.2 \text{ m}) = 31.5 \text{ m}^3$$

Then for two sand filters, the total volume of sand needed is 63 m^3.

Below the filter bed is the underdrain system. The purpose of the underdrain system is to support the filter bed, ensure a uniform filtration rate and collect the filtered water.

The support for the filter bed consists of several gravel layers of different sizes. Use four layers of gravel, sized as shown in Figure 3 - 6. Each layer should be between 60 mm and 120 mm thick.

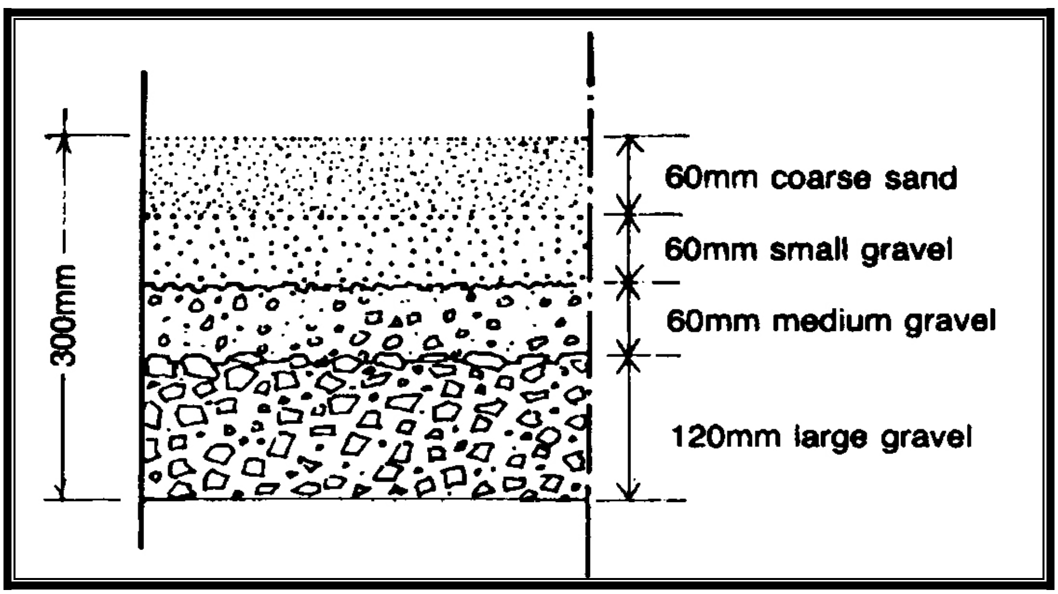


Figure 3 - 6 Filter Support System

The collection system is located below the gravel layers. The underdrain system can be built with bricks and porous concrete or prefabricated concrete slabs as shown in Figure 3 - 7. The distance between the lateral drains must be between 1 m and 2 m, with 2 m the maximum allowable distance. Lay the brick drain tile so that the space between the bricks is 2 to 4 mm, and the distance between the spaces is approximately 0.15 m. See Table 3 - 3 for more specific information.

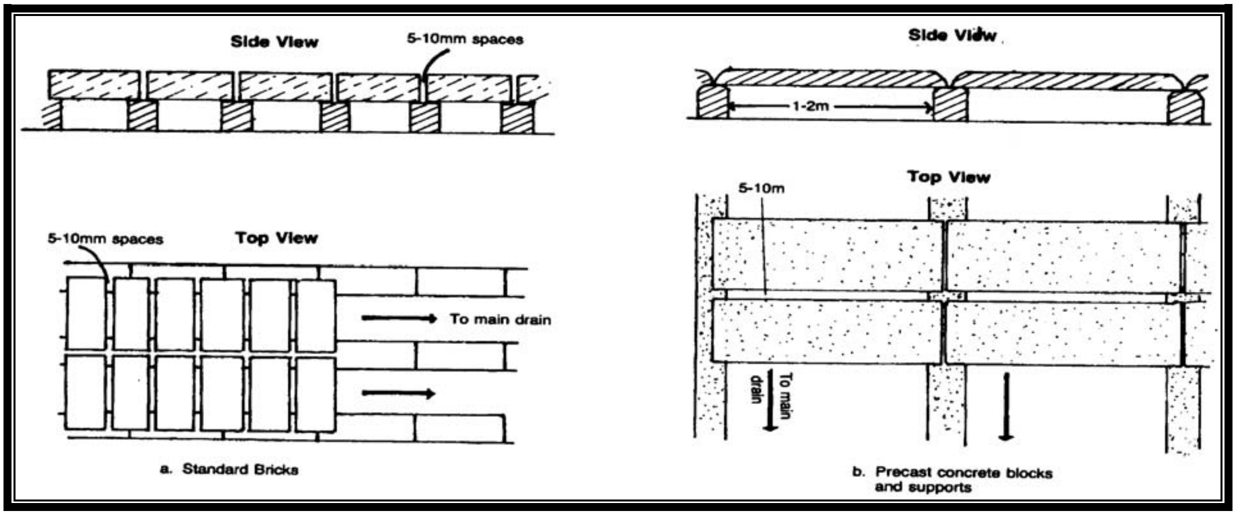


Figure 3 - 7 Underdrain Systems

Table 3 - 3 gives a complete list of the design dimensions of a typical slow sand filter.

Table 3 - 3 Slow Sand Filter Design

Description	Design Limits	Technical Note Example
Area per filter bed	10-100 m^2	26 m^2
Number of filter beds	Minimum 2	2
Water level height in filter	1-1.5 m	1.2 m
Depth of filter bed	1-1.4 m	1.2 m
Depth of underdrain system	0.3-0.5 m	0.46 m
Spacing of laterals in drain	1-2 m	1.5 m
Size of spaces in laterals	2-4 m	3 m
Distance between spaces in laterals	0.1-0.3 m	0.15 m
Filtration rate	0.1-0.2 m/hr	0.1 m/hr
Filter box height	2.5-4 m	3.11 m

By adding the dimensions of the filter box parts, it is possible to calculate the total depth of the filter. The dimensions below are averages.

Freeboard above water level in tank	0.25 m
Water level	1.20 m
Filter Bed	1.20 m
Four layer gravel support	0.30 m
Brick filter bottom	0.16 m
TOTAL	3.11 m

Therefore, the total filter depth will be 3.11 meters.

The rate of filtration should be controlled in order to ensure effective operation of the slow sand filter. The control basically consists of an inlet, a drain and an effluent regulation system. Refer to Figure 3 - 1 while reading this section.

The inlet structure must ensure an even flow of water onto the filter so that the sand bed is not disturbed by falling water. If falling water displaces or destroys the *schmutzdecke*, the filtration process will not work properly. For best results, the flow velocity of water into the filter should be low, e.g. 0.1 meters per second (m/s). A small trough located under the inlet to catch the inflow can be constructed. This catchment is useful in evenly distributing the incoming water. A control valve should be located at the filter inlet to adjust the water level in the tank. A float controlled butterfly valve or a manually operated gate valve can be used for this purpose. The valve is needed to shut down the system for cleaning. See valve A in Figure 3 - 1. An overflow weir should be installed above the water level in the filter box as shown by outlet B in Figure 3 - 1.

Install a drain, controlled by valve C, to remove water from the filter when cleaning is necessary. Locate the drain near the bottom of the inlet trough. There should also be a drain to remove the water in the top layers of the filter bed. See the valve marked D in Figure 3 - 1.

The most important control in the filter system is the effluent control valve E. This valve can be either a gate or butterfly valve. The butterfly valve provides better control as it can respond to small changes in pressure and adjust the filtration by opening more fully as resistance in the filter bed increases. This adjustment allows the total resistance in the bed and valve to remain uniform.

As the filter becomes increasingly loaded, resistance to flow increases. By opening valve E, the total resistance decreases so that the flow in the filter continues over the weir. Open the control valve wide enough to keep an even flow of water over the weir, located at point F. One valve is generally sufficient to provide a uniform flow in the filter. When the flow rate drops below the level of resistance, the sand bed should be cleaned by skimming and raking it. If cleaning does not renew good flow, a sand change may be necessary. This should not be needed for a year or more. Another valve, H, should be installed to run water to waste before the filter bed is ready for operation. Valve G is installed to control the flow from the filter to the clear water well. The clear water well should have a capacity of 30% to 50% of daily water production from the filter.

An overflow weir forms part of the system to control the filtration rate. The crest of the overflow weir should be a little above the top of the sand bed located at point F in Figure 3 - 1.

To refill the filter after cleaning, an inlet for backfilling is installed in the filter as shown by valve J. Refilling the filter from the bottom to the top pushes trapped air upward and out of the filter bed to provide for more efficient filtration.

3.9.1 Construction and Materials

Most slow sand filters are rectangular shaped with vertical walls. Various materials can be used in the construction of slow sand filters. Large filters, which generally are built with reinforced concrete, require more advanced construction techniques and skilled labor. Small filters with a maximum length of 20 m can be built using mass concrete or masonry. Most filters have concrete floors and vertical walls of concrete, masonry, or stonework. The choice depends upon which materials are available and the skills of the labor force working on the construction. Small rectangular filters with vertical walls can be built above ground for convenience. They should be above ground where the groundwater table is high or where solid rock makes excavation difficult. Larger filters should be built into the ground so that the ground provides support for the walls. When designing a rectangular slow sand filter with vertical walls, always keep in mind the following design criteria:

- Prepare a foundation with a minimum depth of 0.3 m to provide support for the walls.

- Plan the depth of the foundation so that there is a minimum distance of 0.5 m between the top of the filter and the ground level to prevent the entrance of children or animals. Generally a distance between 0.5 - 1.0 m is adequate.
- Use a raft design for the foundation. See Figure 3 - 8. The raft foundation gives the filter structure extra strength and helps prevent leaking at the joints.

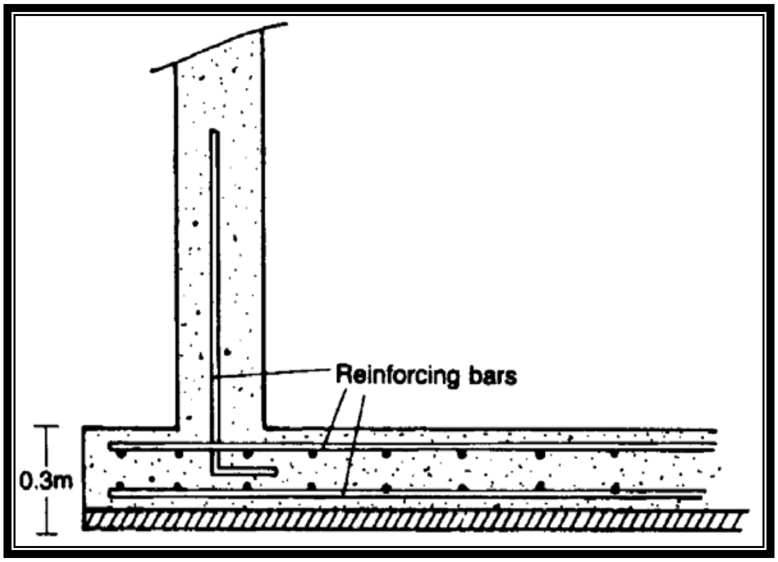


Figure 3 - 8 Raft Foundation for Filter Walls

Once the basic design is set, the amount of materials needed should be determined. If bricks are used for construction, determine the volume in cubic meters (m^3) of the construction and the number of bricks needed per cubic meter. Add a 10% error factor to the calculation to prevent having a shortage of materials. Check with local masons or brick-makers that generally know the number of bricks needed per cubic meter.

When using mass concrete, determine the amount of materials needed by doing the calculations shown in Worksheet C, Appendix B. Make all walls 0.2 to 0.3 m thick. The dimensions given are those used in the earlier example.

Excavated sloping wall structures can also be designed. They are the simplest and most inexpensive filters to install, but they are not as sound structurally as rectangular filters. Do not design a sloping wall structure where the groundwater table is high or where there is doubt about whether the structure will be watertight.

If a sloping wall structure is used, the tank will be completely below ground level. The slope of the walls should be approximately 1:2 (i.e., 1 m of horizontal distance for every 2 m of height). This slope will increase the length of the filter basin and require that a larger land area be used. Piping and valves to control flow must be carefully worked out beforehand, as the flow is caused by gravity.

Suitable lining materials for the walls are masonry, mass concrete, puddle clay or ferrocement sand/cement mixture. Wall thickness will vary with material used. Make sand/cement and mass concrete walls 0.08 m thick, impervious clay walls 0.05 m, and brickwork 0.1 m. Other design features are similar to filters with vertical walls. The area around the filter should be fenced to keep animals away.

3.9.2 Before Construction Begins

Before the actual construction begins, the project designer should provide the following items:

a) A map of the site, where the filter and other treatment units will be constructed similar to Figure 3 - 2. The map should include the location of the water source, other parts of the treatment system, and the water distribution system. It should indicate important landmarks, elevations (or at least the relative differences), and any other information relevant to the project.

b) A list of all labor, materials, and tools needed similar to Table 3 - 1. Ensure that all needed materials are available and at the work site before work begins. Make sure that adequate quantities of materials are accessible to prevent construction delays.

c) A plan view of the filter with all dimensions. Figure 3 - 3 is an example of the type of plan necessary. The dimensions in Figure 3 - 3 are average dimensions for a filter with an area of 26 m^2 as determined in the design example.

Follow the construction steps below. Refer to the diagrams noted during the entire construction process.

a) Begin marking out the site for the filter with stakes and rope. Mark out the length and width of the filter and the trenches planned for the inlet and outlet pipes. The entire area should be staked, as in Figure 3 - 9, before construction begins.

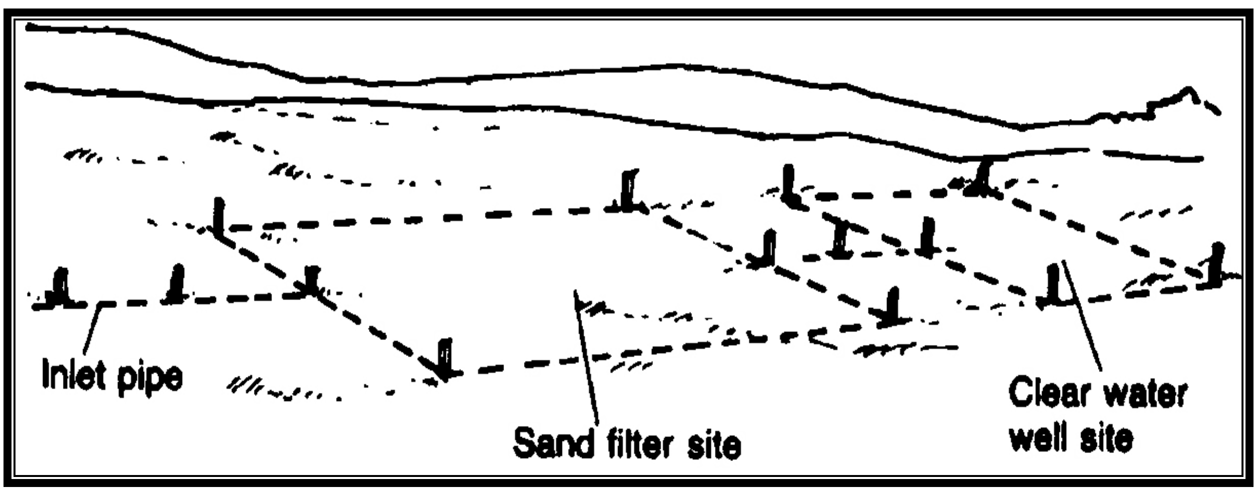


Figure 3 - 9 Staking Construction Site

b) Dig out the base for the foundation. If a vertical wall structure is chosen, the foundation should be at least 0.3 m deep. If conditions permit, dig the foundation deeper to provide more support for the walls. The foundation cannot be too deep, particularly if the water table is high or if a subsurface rock layer is located near the ground surface. All parts of the system should be constructed carefully. Take care to provide for correct elevations so that gravity flow through the filter, valves and piping is maintained.

If a sloped wall structure is chosen, excavation should continue down to the full depth of the filter. The walls should be sloped as digging occurs to prevent caving of the sides.

c) Concrete pipe or ferrocement filters can be built either above or below ground. The filter base can be built below ground for added structural support. After reaching the desired depth, level the floor of the excavated area. At this time, begin to excavate a trench for the filter outlet so that installation will be easier as work progresses. Do not make the trench too wide but leave sufficient room for one person to work comfortably. When completing the excavation, begin setting up the formwork for the foundation and walls (0.25 m thick). If mass concrete is to be used, use wooden forms and oil them thoroughly before pouring any concrete. For ferrocement structures, the formwork will be the wire itself.

When setting up the formwork, be sure to leave a place for an inlet pipe. And if building a rectangular filter, provide for a small trough for receiving the inflow. See Figure 3 - 10. The trough prevents disturbance of the filter bed and *schmutzdecke*, which can be caused by the jet of water from a pipe.

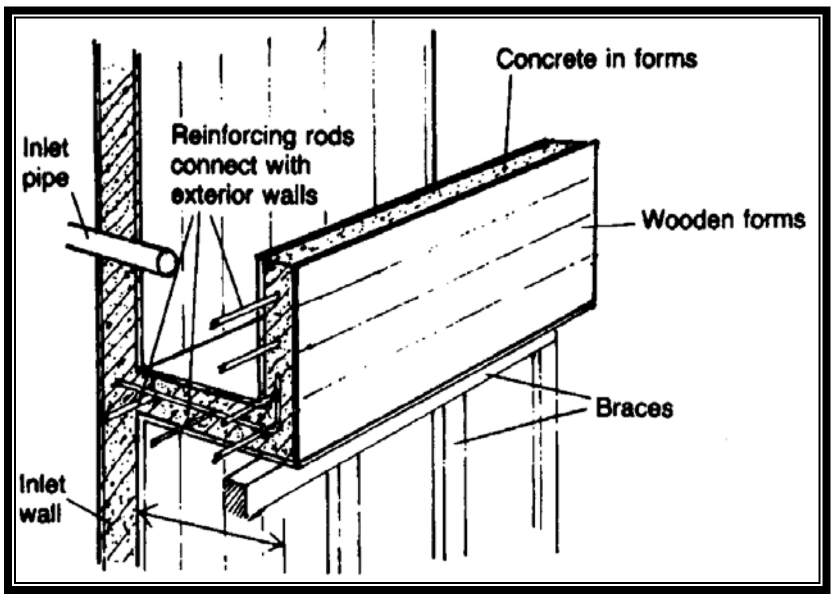


Figure 3 - 10 Inlet Trough

For rectangular filters, a concrete raft foundation like that in Figure 3 - 11 should be constructed. The raft foundation provides for equal settling of the filter box and prevents water loss through the joint between the wall and the foundation. When laying the foundation, use 8 mm diameter reinforcing rods placed 200 mm apart. The reinforcing bars should be placed in a grid pattern at the top and bottom of the floor as shown in Figure 3 - 11. For all concrete work, mix ingredients in the proportion of one part cement to two parts sand to three parts gravel. After pouring the foundation, the rest of the filter structure can be built. For mass concrete filters, use the same mixture of ingredients used for the foundation. Fill in the forms completely, and let the cement cure for at least 10 days. For increased strength, the concrete should cure at least two weeks. Keep the concrete moist during the curing process to prevent cracks and to allow it to gain full strength.

If bricks are used to build the walls, be sure to keep them vertical. A plumb bob should be used to check the walls after each two lines of bricks are laid. Make sure that vertical joints do not line up. After all bricks are laid, prepare a mixture of mortar using 1 part cement and 3 parts sand. Plaster the walls of the basin with the mortar to form a lining 300 mm thick. For circular ferrocement tank, use mesh to form walls 0.06 m to 0.12 m thick. To cover the wire mesh, prepare a mixture of cement using one part cement to two parts sand. Add water to form a paste-like consistency, or add approximately 0.4 parts water by weight. Apply the mixture to the mesh with a trowel. Ferrocement should be kept moist during the seven days required for curing.

Sloping wall structures follow similar wall construction techniques. The walls should be excavated for a 1:2 slope and a lining should be applied to the walls. Lining thickness ranges from 0.05 to 0.15 m.

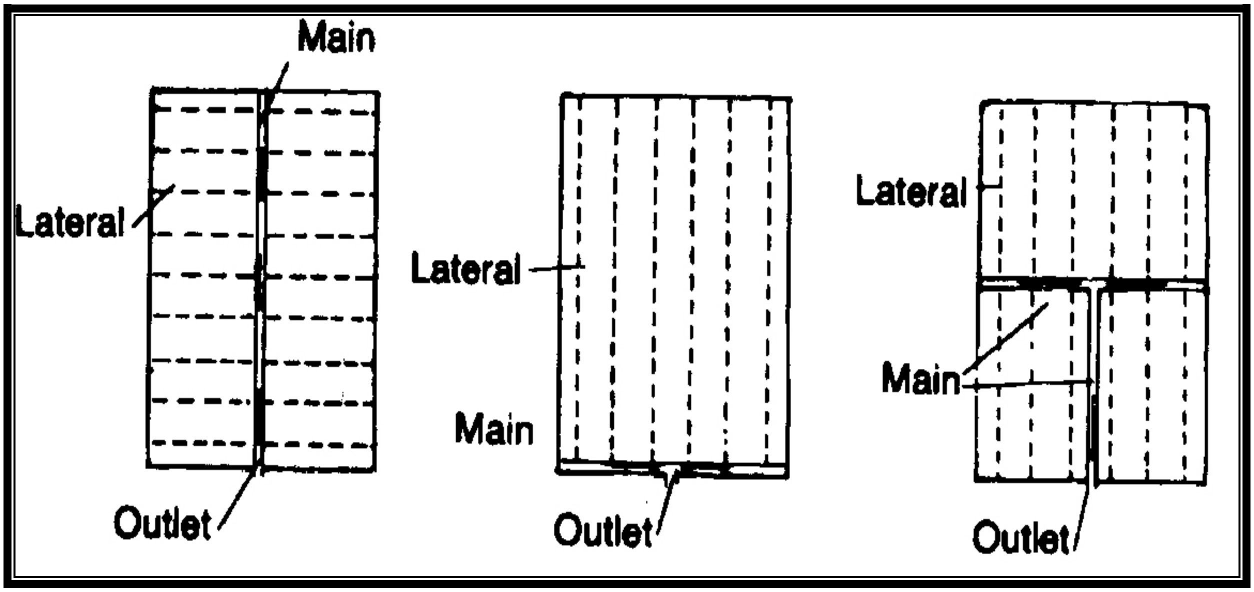


Figure 3 - 11 Common Arrangements for the Main Drain of a Slow Sand Filter

3.10 Underdrainage System

Once the basic structure is completed, prepare the system of underdrains for the sand filter as shown in Figure 3 - 7. Several different types of materials can be used for the lateral drains. Porous or perforated drainage tiles, open-joint tile and cement pipe, and perforated concrete or perforated PVC pipe are all acceptable materials. Bricks may be used for construction of lateral drains. Drains made with brick should have a width of approximately 230 mm.

In small filters and especially in ferrocement filters, perforated pipe can be used for the main drain. In larger filters, use concrete. One of the best methods is to build a concrete drain embedded into the floor of the filter bed.

When placing laterals, space them at 1 to 2 m. The hole sizes in the laterals should be 2 to 4 mm and have a space between them of 0.1 to 0.3 m. Figure 3 - 1 shows a drainage system using bricks for drains. The velocity of water through the lateral and main drain will be approximately 0.3 m/s.

After the drainage system has been put in place, install several layers of gravel over the drains. Use stones that are as hard and round as possible. Place a 120 mm layer of coarse gravel sized 18 to 36 mm over the top of the drain. Then place three 60 mm layers of fine gravel on top of the bottom layer. Use 6 to 12 mm gravel in the second layer, 2 to 4 mm gravel in the third, and 0.7 to 1.4 mm gravel in the top layer. Once the gravel is in place, the underdrainage system is complete. Be sure that the drainage system is well constructed. Once the gravel and sand layer is placed on top, it is difficult to reach the drains for any needed repairs.

3.11 The Sand Bed

Construction of the sand bed is one of the most important parts of slow sand filter construction. Properly sized sand should already be at the site when construction begins. It is necessary to ensure the sand contains no clay, loam, or organic matter.

In some cases, it may be necessary to wash the sand to ensure its quality. If so, place the sand to be washed in a box, and let water flow through it from the bottom. Rake the sand to distribute it evenly, and ensure that all of it is washed. Wash the sand until the water overflowing the box is clear.

Fill the filter box with sand. The depth of the filter bed should range between 1.0 and 1.4 m so that frequent changing of the sand is unnecessary. When the filter bed is thick enough, level the sand.

3.12 Filter Control Systems

The filter control system regulates the flow of water into and out of the sand filter and allows effective operation and maintenance. Refer to Figure 3 - 12 when reading these directions. Put piping in place as walls are built.

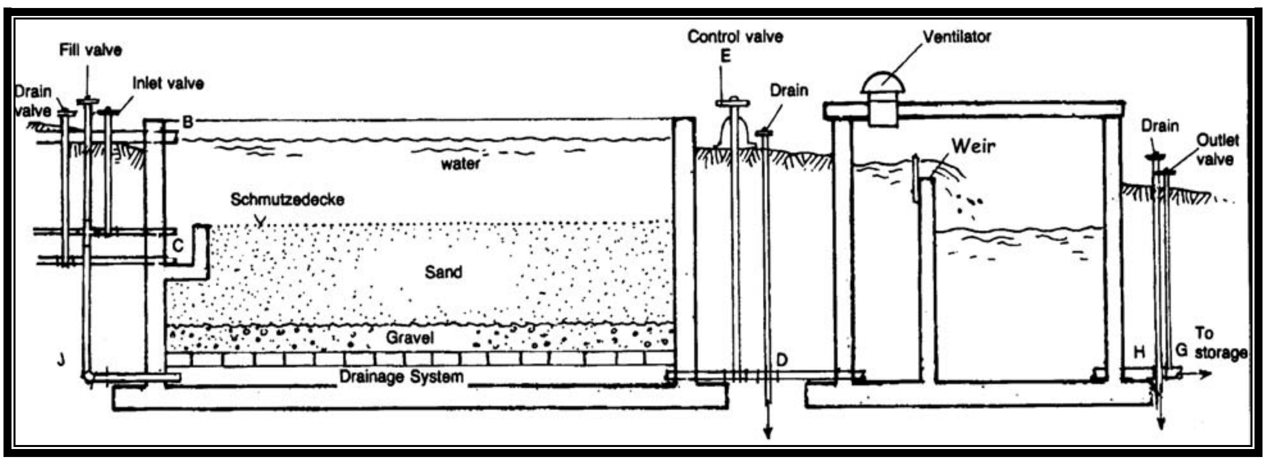


Figure 3 - 12 Slow Sand Filter with Valve System and Clear Water Well

a) Install the inlet pipe A. Use a 50 to 100 mm diameter pipe and attach a cut-off valve to control the flow of water into the tank.

b) Install an overflow pipe B, approximately 1.25 m above the filter bed surface. The height ensures that the water in the tank will be 1.2 m deep.

c) Place a drainpipe C at the bottom of the inlet trough so that the filter can be drained for cleaning. The drainpipe should have a tap that is protected from children.

d) At the outlet end of the sedimentation basin, place an outlet pipe of equal diameter to the inlet. The filter outlet structure needs a cut-off or control valve, located at point E. The best choice for a control valve is a butterfly valve as it permits a more precise regulation of flow through the filter. A gate valve can be used. These valves are important in controlling water flow in the filter, especially as resistance builds up in the filtration process.

e) Install another valve at point D. This valve permits the drainage of all water in the sand layers before the water goes to storage. This valve is important for cleaning out the filter.

f) Construct an overflow weir and clear water well. For small systems, the clear well may serve as storage for the completed system. In large systems, a storage tank should be constructed. Build the clear well and weir from the same materials as the filter and follow similar construction steps. The tank should be at least 2.5 m deep and hold 30 to 50% of daily water production. Ventilation, or preferably an access opening, should be provided as shown in Figure 3 - 12.

g) The overflow weir should be constructed so that its crest is above the sand layer. This weir serves the purpose of maintaining a certain level of water in the filter and providing for aeration of the water.

h) Finally, three more valves should be installed in the filter system. Valve G is a cut-off valve, which controls water flow from the clear water well to storage and distribution. Valve H allows raw water to run from the filter to waste. A valve for backfilling the filter should be installed at the base of the underdrain system as shown by J. This pipe is used to refill the filter after cleaning. By forcing water up from the bottom, air caught in the filter bed is forced out.

Ferrocement filters are usually of small capacity and will not generally require as complicated a control system as the large rectangular filter. The same general construction steps should be followed, however, for the filter bed, underdrain, and outlet structure to storage.

3.13 Operation and Maintenance

A well-designed and well-constructed slow sand filter requires a simple but essential program of operation and maintenance. Local workers with little training should be able to perform operation and maintenance of slow sand filters. Neither expensive machinery nor highly skilled labor is needed. The basic steps and procedures outlined herein will help to ensure that sand filters function properly and that good quality water is produced.

The procedures for operating and maintaining slow sand filters include the following:

- Initial start-up of the filter
- Daily operation and control of water flow
- Cleaning the filter
- Replacing the sand

3.13.1 Filter Start-up and Operation

Once the filter is constructed, it must be put into operation. Preparation of the filter takes several weeks, as the sand bed must be adequately prepared to act as a biological filter.

Close all outlet valves in the filter system and add potable water to the filter from the bottom as shown in Figure 3 – 13 in valve J. The water that enters from the bottom forces air bubbles out of the filter bed and ensures that all grains of sand are in contact with water. Continue adding water until the water level is approximately 0.1 m above the sand bed.

When the water reaches 0.1 m above the sand, begin to let water in through the raw water inlet (valve A). At first, let the water in very slowly so as not to disturb the sand layer. Once the water deepens, the rate of inlet flow can increase.

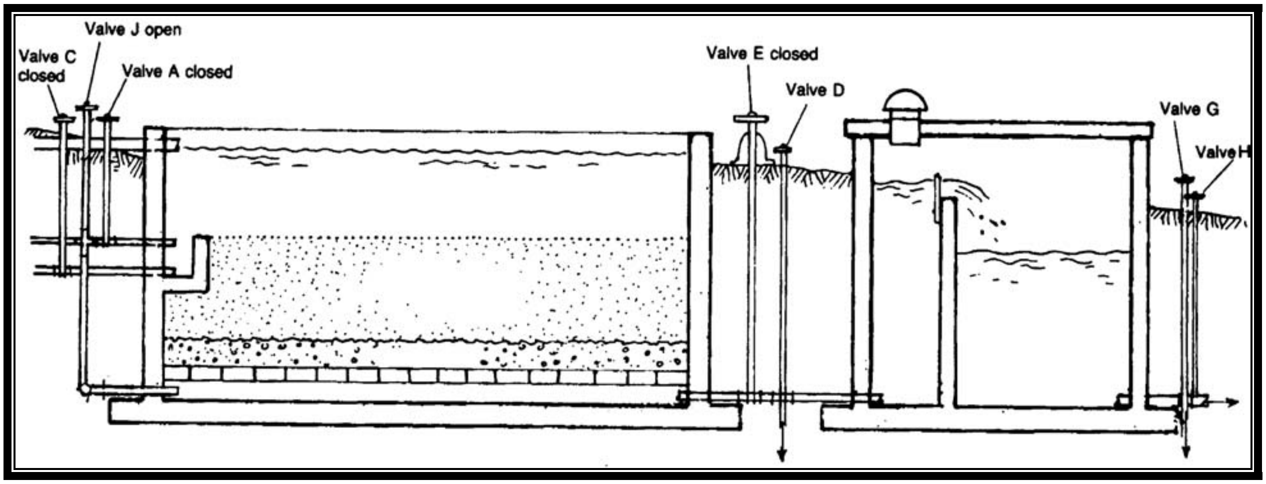


Figure 3 - 13 Filling the Slow Sand Filter

When the water reaches the working level, open valve D shown in Figure 3 - 13, and let the water run to waste through valve G at a rate of about one-quarter the normal filtration rate. Control the flow with the filter-regulating valve. Run the filter for several weeks to allow the *schmutzdecke* to form on the sand. This technique is called the “ripening process.”

During the ripening process, gradually increase the filtration rate until it reaches the design rate. Test the effluent water to see that the filter is working properly. Once the filter works, close the drain, and open the valve that directs the water to the clear water tank.

Regulate the flow of water in the filter using valve E in Figure 3 - 13. When the filter first begins operation, it will operate with the regulatory valve almost completely closed. As the filter bed becomes partially clogged, the valve is opened a little more each day to keep a constant head in the reservoir and a constant flow rate. Open the valve as needed. Once the valve is completely open and flow begins to decrease, the filter should be cleaned.

3.13.2 Cleaning the Filter

After several months of operation, a filter will need cleaning. For cleaning the filter, follow these steps:

- Close inlet valve A, shown in Figure 3 - 14, to stop the flow of water to the filter. As the head in the water reservoir drops, the rate of filtration decreases. Let filtration continue for a few hours, usually overnight.
- The next morning, close valve G that controls the effluent flow to the clear water tank and open valve D, which lets the water flow to waste. Run the water to waste until the level of water in the filter bed is 0.1 to 0.2 m below the surface of the filter bed.
- As soon as the top layer of the filter is exposed, begin removing it using flat-nosed shovels (see Figure 3 - 15). Carefully remove the *schmutzdecke* and the surface sand sticking to it by stripping it off and piling it into heaps. Remove as little sand as possible, not more than 0.1 to 0.2 m. Remove the waste with wheelbarrows, large baskets, or buckets. See Figure 3 - 15.

- Clean the filter as quickly as possible to prevent deterioration of the bed. The quicker the bed is cleaned, the less the bacteria in the lower layers will be disturbed. Re-ripening the bed is much quicker in this case. Quick cleaning of the filter prevents damage caused by scavenging birds that may be attracted to the filter bed. These birds contaminate the surface of the bed and disturb the sand at a greater depth than is affected by scraping.
- After scraping and removing the schmutzdecke, level the sand in the filter.
- To restart the filter, follow the same steps as for start-up. The time required for both backfilling and re-ripening is much less than needed for initially putting the filter into operation. Backfilling requires only a few hours and re-ripening a few days.

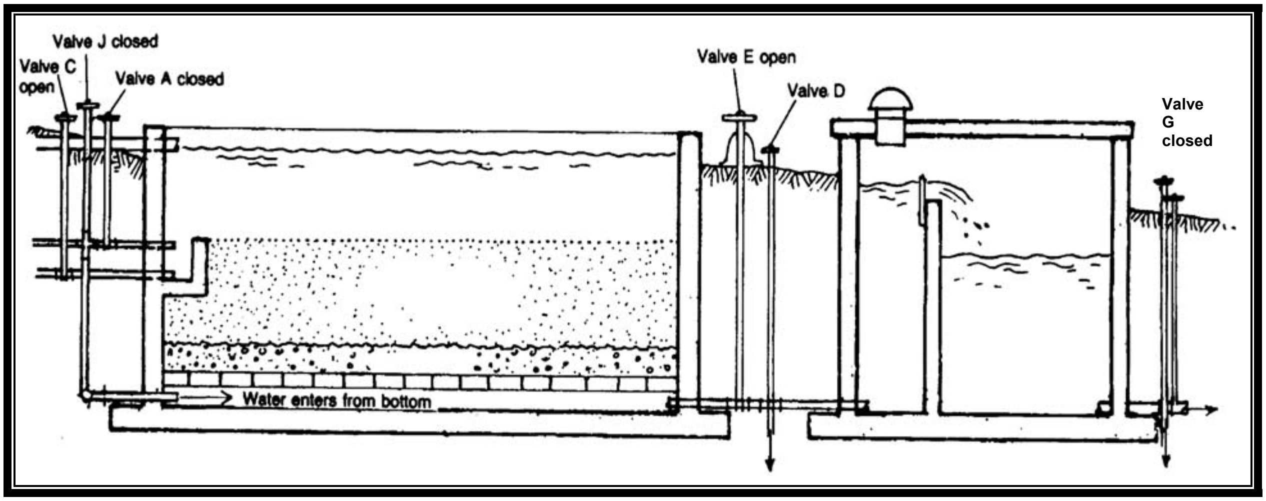


Figure 3 - 14 Draining the Filter for Cleaning

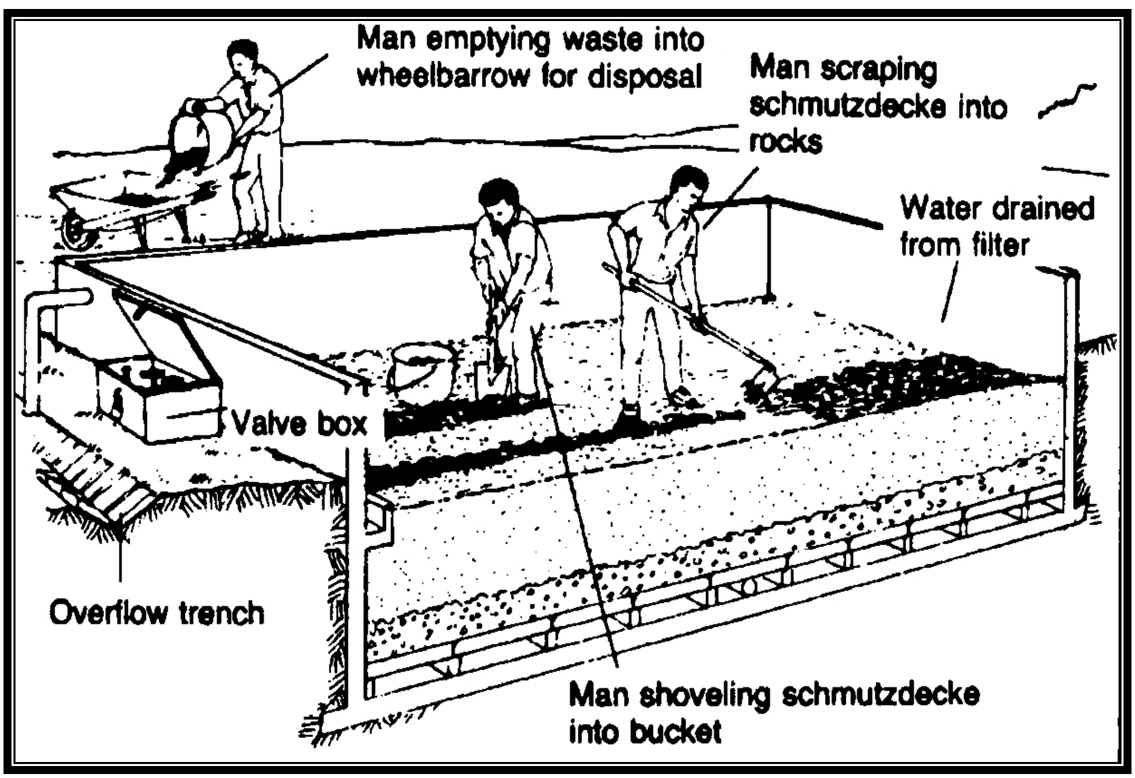


Figure 3 - 15 Cleaning the Schmutzdecke Layer

3.13.3 Replacing the Sand

After 20 to 30 scrapings, or several years, the filter bed will reach its minimum thickness (0.5 m to 0.8 m above the filter gravel layer), and new or washed filter sand should be added to the filter bed. Sand is replaced through a process called "throwing over" and is done as follows:

- Dig a strip into the remaining sand layer, as shown in Figure 3 - 16. Dig down a maximum of 0.3 to 0.5 m being sure not to disturb the gravel layer.
- Place the excavated sand to the side, and add new filter sand to the trench. Excavate a second strip next to the first. Throw the sand excavated from this second trench on top of the new sand in the first. Follow this process until the whole filter is refilled with new sand, and the upper 0.5 m is made up of the old sand taken from the bottom. The last excavated strip is covered with the sand taken from the excavation of the first strip.
- Once re-sanding is completed and the filter bed leveled, the re-ripening process can begin. Because a layer of sand containing some beneficial bacteria is placed at the top of the filter bed, the re-ripening process should not take as long as for a new filter.

Where sand is difficult to obtain or expensive, the sand taken from the filter can be washed and stored. The scrapings should be washed as soon as they are taken from the filter to prevent taste- and odor-producing substances from developing, which are impossible to remove later. Care should be taken not to lose too many small sand particles during the washing.

The manual cleaning and other operation and maintenance work described in this section do not require special skills or equipment, especially when small filters are being used. Large filters may require many workers and the expense and time required are very demanding for rural communities. Mechanical cleaners are available, but are too expensive and difficult to maintain for small treatment systems.

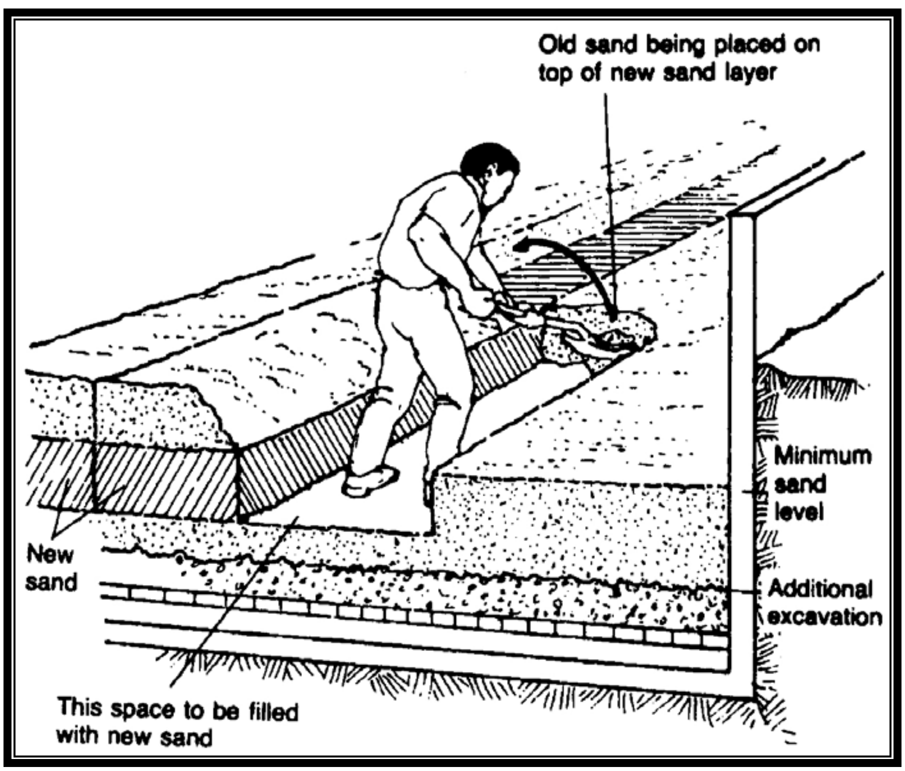


Figure 3 - 16 Turning the Filter Layer

A slow sand filter is an effective method of treatment for a rural water supply system. The filter is easy to operate and maintain with local skills and labor. However, a skilled technician should be available to design and construct the filter to ensure that it works correctly. Slow sand filters are useful in most areas where there is sufficient good quality sand and where land is available. If possible, the site should provide gravity flow for operation to the users.

The filters mentioned in this technical note are examples of design suggestions. The choice of sand filter design will depend on the site available, materials and local skills.

3.14 Summary

Sedimentation basins and slow sand filtration may be the only practical treatment technologies for rural areas, small and medium-sized municipalities and low-income urban areas facing important problems in the provision of good quality, efficient and environmentally friendly water supply. The use and application of this treatment technique is not beyond the educational levels of most rural inhabitants when proper training is provided. For project with short construction schedule duration, the use of vendor supplied treatment systems and pre-developed operational manuals may be the most effective method for achieving a safe public water supply.

SECTION 4

DESIGNING SMALL DISINFECTION UNITS

EXECUTIVE SUMMARY

Disinfection involves the removal, destruction, or inactivation of disease causing organism, and is often the only form of treatment required for a groundwater system. For small systems in developing countries it is necessary to included chlorination because of the potential for contamination caused by public use or recontamination of the storage or distribution system water supply through the lack of administrative control. This section describes various types of chlorination systems including: pot chlorinators, drip-feed chlorinators, floating bowl chlorinators, tablet and tee-chlorinators, and chlorine pump-injection systems. The applicability of each system to a water system project is dependent upon the field conditions and the economic viability of the community. Usually, in developing nations, simple is best. However, one theme remains the same. Chlorination disinfection methods must always be provided on systems furnished by the United States.

4.1 Community Disinfection Units

Disinfection of ground and surface water is often necessary to insure drinking water is free from microorganisms that can cause disease. Drinking water may be disinfected by adding chlorine to the water. Chlorine is used because it destroys pathogens quickly and is available in most areas at a moderate cost.

This section describes the design of three basic methods for chlorinating community water supplies:

- A pot chlorinator;
- A drip feed chlorinator, which is used to disinfect water in individual and community wells, and cisterns;
- A floating bowl chlorinator, which feeds a chlorine solution into the water supply;
- Chlorine metering pump; and
- A tee chlorinator.

These methods are inexpensive and do not require skilled labor to operate. However, adequate supervision must be available to ensure the chlorinators work satisfactorily and that sufficient chlorine is added to make the water safe.

The design process should result in the following items:

a) A list of all materials and tools needed for the chlorinators. A sample list of materials appears in Table 4 - 1 for a pot chlorinator and in Table 4 - 2 for a Drip Feed Chlorinator

b) Table 4 - 3 for a floating bowl chlorinator.

c) A detailed plan of each type of chlorinator similar to those shown in Figure 4 - 1 and Figure 4 - 2.

Table 4 - 1 Materials List for Pot Chlorinator

Item	Description	Quantity	Estimated Cost
Labor	Members of Household		
Supplies	Earthen Jar Gravel Chlorine Bleach Clean Sand Rope or Wire	________ ________ ________ ________	________ ________ ________ ________
Tools	Hammer Pliers Wire Cutters Knife	________ ________ ________	________ ________ ________
Total Estimated Cost = $			

Table 4 – 2 Materials List for a Drip Feed Chlorinator

Item	Description	Quantity	Estimated Cost
Labor	Foreman		
	Laborers		
Supplies	5 gallon plastic jerry can		
	Rubber cork or stopper		
	One small glass tee tube 6 to 9 mm		
	One small tube 6 to 9 mm		
	Flexible hose		
	Wood or plastic float		
	Wood or plastic cover for hole		
	Screen or sieve over hole		
Tools	Hardware		
	Saw		
	Nails		
	Drill		
	Knife		
	Buckets		
	Total Estimated Cost = $		

Table 4 – 3 Materials List for a Floating Bowl Chlorinator

Item	Description	Quantity	Estimated Cost
Labor	Foreman		
	Laborers		
Supplies	55 gallon barrel		
	Rubber cork or stopper		
	One small tube 6mm to 9 mm		
	Two small test tubes 3 mm each		
	Small stones		
	Flexible hose		
	String		
	Wood or plastic bowl		
	Drain plug		
	Outlet connection		
	Planks and other wood for support		
	Paint		
	Latex or rubber base		
Tools	Hardware		
	Saw		
	Nails		
	Drill		
	Knife		
	Buckets		
	Paintbrush		
	Total Estimated Cost = $		

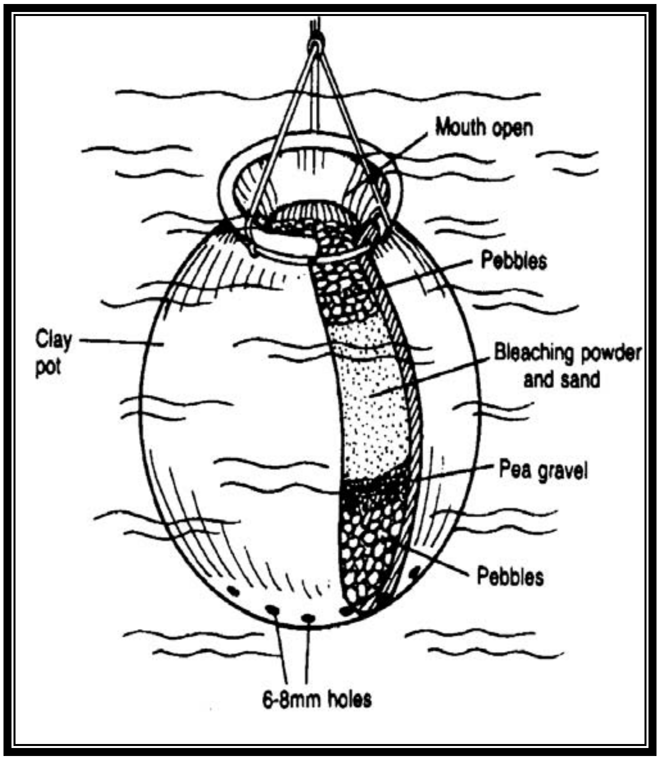


Figure 4 - 1 Pot Chlorinator

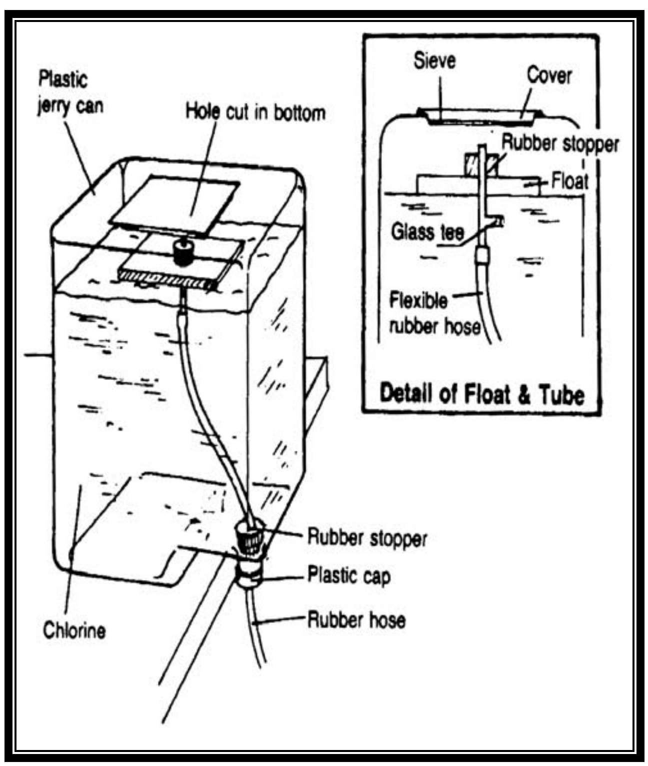


Figure 4 - 2 Drip Feed Chlorinator

4.2 Chlorine/Chlorinators

Several types of chlorine are available for use in disinfection. The choice of which type to use depends primarily on what is readily available at a low cost. The most common forms of chlorine for disinfection in small water supplies is sodium hypochlorite (household bleach) in the liquid form, and calcium hypochlorite (such as High Test Hypochlorite (HTH) for swimming pools) in the powder form. Disinfection power is determined by the amount of available chlorine that each form produces. The available chlorine in these compounds varies from 20% to approximately 5%. Table 4 - 4 lists the various types of chlorine and their strengths.

Table 4 - 4 Chlorine Compounds

Compound	Available Chlorine	Basic Characteristics
High Test Hypochlorite (HTH)	70%	Retains strength for over a year under normal storage conditions; less common on market.
Chlorinated Lime (Bleaching Powder)	33-37%	Very unstable; loses strength quickly with exposure to air, light or moisture; should be stored in a dark, cool, dry place in rust resistant containers; more readily available than HTH.
Sodium Hypochlorite Solutions a. Commercial b. Household (Laundry Bleach)	12-15% 3-5%	Like bleaching powder, very unstable and the same precautions must be taken; readily available in most areas.

For chlorination to be effective, a sufficient amount of chlorine must be added to the water to provide a residual. Generally, a free available chlorine residual (FAC) of 0.4 mg/L after a contact time of 30 minutes will destroy most pathogenic or disease causing bacteria. To test for chlorine residual, a field-testing kit is needed. If a kit is unavailable, a guess can be made by taste and smell. If the water has a slight chlorine taste and odor, then adequate chlorination can be assumed.

4.2.1 Pot Chlorinators

Pot chlorinators are effective for disinfecting water in contaminated shallow dug wells and surface water. The simplest type of chlorinator is an open-mouthed pot containing a mixture of sand and bleaching powder. The pot is simply lowered into the well by a rope and left to hang underwater. See Figure 4 - 1.

To make a pot chlorinator, use a plastic or earthen jar with a capacity of 7 to 10 liters. The jar does not need a cover. With a sharp object, chisel, or hand drill, make seven 6 mm to 8 mm holes in the bottom of the pot. The pot should be half-filled with pebbles and pea gravel with approximately 20 mm to 40 mm diameter. Next, a mixture of sand and bleaching powder is made. The mixture should contain one part bleaching powder to two parts sand (1:2) and should fill the pot to the neck. After placing the chlorine-sand mixture, a thin layer of pea gravel is placed on top in order to fill the pot almost to the neck. Finally, attach wire or rope to the jar as shown so that the pot can be attached to a rope or hook and be lowered into the well or tank. Ensure the pot is firmly secured to prevent it from being lost in the storage tank or well.

The pot, containing 1.5 kilograms (kg) of chlorine, will effectively chlorinate for one week a storage tank or well from which water is taken at a rate of 1000 to 1500 L/day. Where volumes are smaller, the chlorination process will last longer. In larger wells, an additional pot or several pots may need to be added to adequately kill pathogenic organisms. Pot chlorinators can be used for disinfecting water in cisterns as well.

4.2.2 Drip Feed Chlorinators

Another method of disinfection of water in wells, cisterns, and small reservoirs or tanks is the drip feed method. A typical drip feed chlorinator is shown in Figure 4 - 2. A small drip feed chlorinator can be made easily from plastic cans, bottles, or jars available in most areas. The spout of the container serves as the outlet and the bottom of the jar is cut out so that solution can be added and for access to the inside of the can.

A drip chlorinator requires a small float, plastic or rubber tubing, and stoppers. Choose a material to serve as a float, such as plastic, styrofoam, or wood. The spout of the container serves as the outlet for the chlorine solution. A rubber stopper is placed in the middle of the float and a piece of hard tubing is placed through the stopper. Glass, brass, or plastic tubing can be used. The tubing should extend below the float into the solution where a small hole is placed in the tube for the solution to enter, unless a tee is available as indicated in Figure 4 - 2.

Small diameter flexible tubing is attached to the stopper tubing as illustrated in the Figure 4 - 2. The hose extends from the hard tube to the outlet. It passes through a rubber or cork stopper placed in the container's neck and a plastic cap that covers the spout. Choose a long tube so that it extends from the chlorinator to the water that is to be disinfected.

Solution feed, drip chlorinators use the batch method of mixing to disinfect water in storage tanks or reservoirs. The batch method involves mixing a specific volume of water with a certain strength and volume of chlorine and adding it to the water through a gravity flow system. The strength of the batch should be about 1 to 2%.

Use 2 to 5% chlorine bleach to fill the chlorinator. The chlorine solution can be used directly at full strength. No water should be added. To control the rate of flow, a small clamp is placed on the discharge hose to regulate the flow. If an adjustable clamp is not available, make one from two pieces of aluminum and two aluminum nuts and bolts. Place the clamp around the outlet hose and tighten it to cut off all flow during installation. Loosen the clamp to get the desired drip rate. Set it at a slow drip. The chlorinator should be hung in a well or cistern with the hose extending into the water to be treated. If a wire is needed to hang the chlorinator, it can be attached to the storage tank, well or cistern and the container hung inside. The chlorinator must be refilled with chlorine bleach when it is nearly empty.

4.2.3 Floating Bowl Chlorinators

Many commercial chlorinators are available for disinfecting both small and large water supplies. If available, commercial systems may be an economical and efficient method of disinfecting piped water supplies. Where such equipment is difficult to obtain and/or too costly for the community, homemade solution feeders that provide close control of the solution and a low rate of feed can be made locally. One device is the floating bowl chlorinator shown in Figure 4 – 3.

Floating bowl chlorinators hold a much larger volume of chlorine solution than drip feed chlorinators and are used to add chlorine at a constant rate to water in a tank or in a low-pressure pipeline.

The floating bowl chlorinator consists of a small tank, generally a 55-gallon drum, fitted with devices for controlling the rate of flow from the tank to the reservoir. See Figure 4 - 4. Use a 55-gallon plastic (preferred) or steel drum for this purpose, although a larger concrete tank can also be used. Prepare the tank for use by removing the top cover or largest bung seal, and clean out the tank. It should be washed with a 1% chlorine solution. The chlorine solution should stand in the barrel for no less than 30 minutes. Empty the barrel. If using a steel drum, paint the inside with a latex or rubber base paint. Painting the inside of the drum reduces rusting of the steel surface, which would reduce the quality of the water supply.

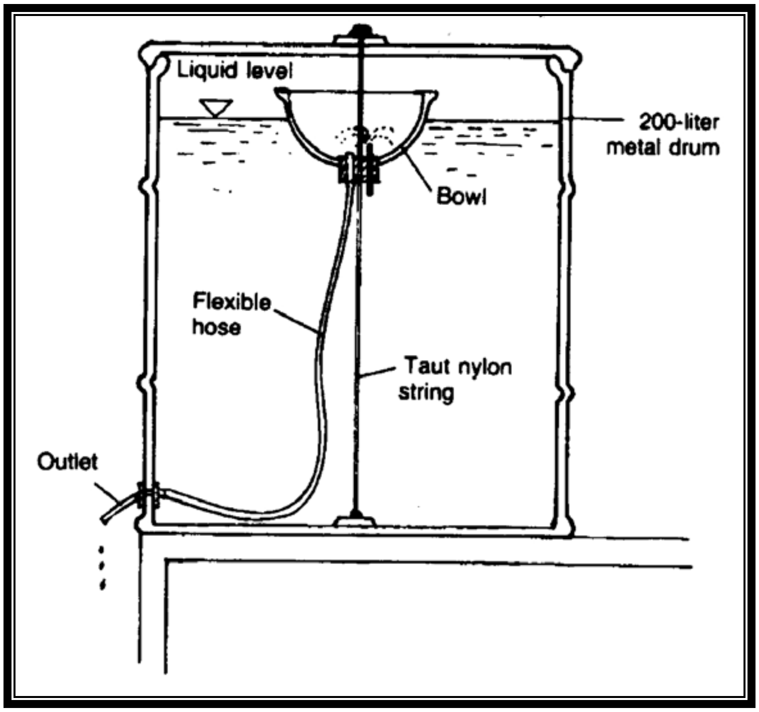


Figure 4 - 3 Floating Bowl Chlorinator

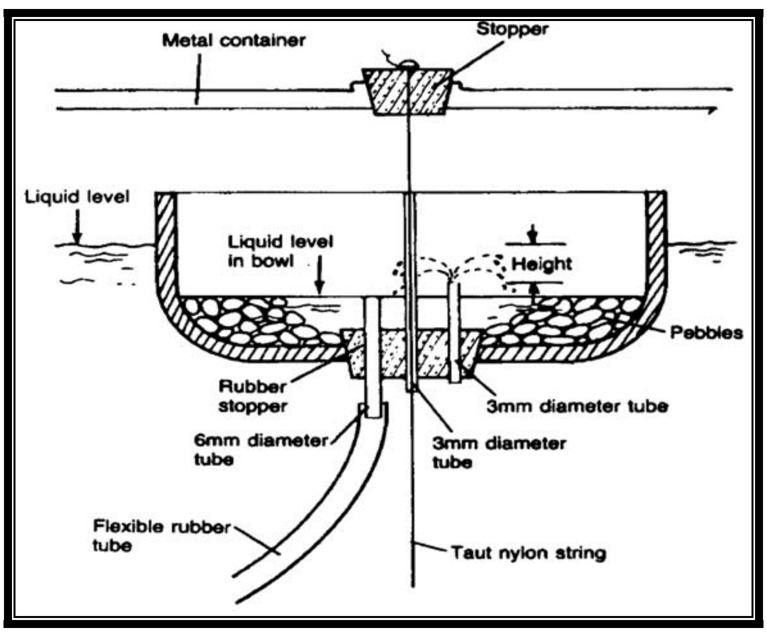


Figure 4 - 4 Detail of a Floating Bowl Chlorinator

After the paint is dry, a small 6-mm hole should be placed in the side of the barrel, and a 10-mm hole should be placed in the bottom of the barrel to serve as a drain. The system must be drained periodically for cleaning. A cover must be placed over the top of the tank to keep out light. The cover should not be airtight to allow air entry.

To feed the chlorine into the water supply, make a floating bowl. The floating bowl arrangement should be designed to ensure that the chlorine solution trickles from the outlet at a constant rate. Use a plastic bowl, or cut out the bottom of a plastic bottle to form the floating bowl. Almost any material that floats will be adequate. A hole must be place in the bottom of the bowl and stopped with a rubber stopper, or a large piece of cork. The size of the hole will depend on the cork size. Use a stopper borer or hand drill; make a hole in the middle of the float to fit a medium sized rubber or cork stopper.

The cork should be large enough for three tubes to pass through. One tube should be 6 to 9 m in diameter and the other two 3 mm. Before placing the stopper in the opening, push the three short tubes through the stopper. The rubber or cork stopper must be wedged into the opening to fit securely without leaking. See Figure 4 - 5.

Choose glass, plastic, brass, or copper tubes. The tubes should be pushed through the cork so that one end opens into the bowl. The larger tube, 6 - 9mm in diameter, should be connected to a flexible hose that runs to the outlet. It should not extend beyond the face of the topside of the stopper or the small stones used for weight. A smaller tube, 3 mm in diameter, should be pushed through the cork until the top of it is slightly below the liquid level in the tank. The other 3 mm tube should be higher than the other two tubes as shown in Figure 4 - 5.

To install the floating bowl in the tank, first connect one end of the flexible rubber hose to the largest diameter tube. Connect the other end of the hose to a small drip outlet. The drip outlet can be made of plastic with a watertight joint. Placing a clamp over the flexible tube can provide for flow control. Tightening the clamp will slow the flow; loosening it will increase the flow.

Finally, a string should run through the third tube, which should be placed through the center of the cork. The string is secured to the top and bottom of the barrel as shown in Figure 4 - 3 and Figure 4 - 4. Secure one end of the nylon string to the bottom of the tank. The free end is passed through the center 3-mm tube in the stopper, shown in Figure 4 - 4. Pull the string as tight as possible, and attach it to a wooden cross piece over the top of the barrel. Secure it adequately, so it can be separated from the cover to refill the barrel without disconnecting the bowl. The string keeps the bowl in the center of the tank and prevents it from catching on the sides. An outlet is placed on the lower side of the tank, and the flexible hose is stretched out. This type of connection permits the water to drip into a funnel system that leads to the water storage.

Figure 4 - 5 shows a bowl without a guide string. The chlorinator is easier to make without the guide string, but the bowl may drift to the sides of the barrel. If there are no ridges or plugs in the sides that could prevent the bowl from moving downward as the chlorine solution is used, the chlorinator should work.

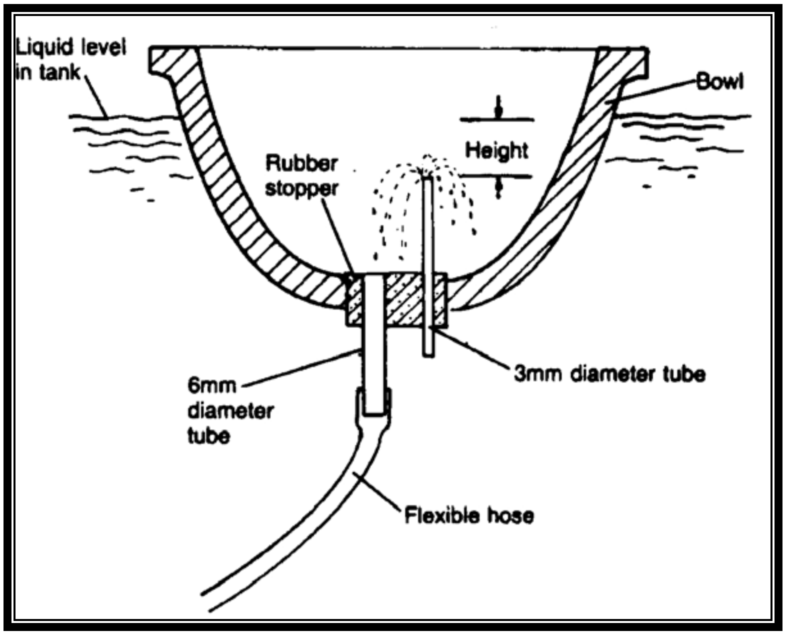


Figure 4 - 5 Floating Bowl Chlorinator

The chlorine solution should then be prepared, and the tank filled almost to the top with a 1% chlorine solution. To determine the amount of chlorine to add to make a 1% solution, use the following calculation:

$$K = \frac{\text{(\% Strength of solution desired) X (Liters of solution required)}}{\text{(\% Available chorine in compound)}}$$

Where **K** is the kilograms of chlorine required. For example, to prepare 200 liters of a 1% solution using hypochlorite powder with 70% available chlorine, find the amount of chlorine, which must be added as shown below.

$$K = \frac{1\% \text{ x } 200 \text{ liters}}{70\%} = \frac{0.01 \text{ x } 200 \text{ liters}}{0.70} = 3 \text{ kg}$$

In other words, 3 kg of hypochlorite powder would have to be added to 200 liters of water to make a 1% solution.

In a like manner, if the bleaching powder were to have 35% available chlorine (as determined from the label), the calculation would be:

$$K = \frac{1\% \text{ x } 200 \text{ liters}}{35\%} = \frac{0.01 \text{ x } 200 \text{ liters}}{0.35} = 5.5 \text{ kg}$$

Add the solution to the tank. Then weight the bowl using small stones so that it floats steadily and straight. Figure 4 - 4 shows this technique. To function properly, the chlorinator must be effectively maintained.

Build a small platform above the reservoir holding the water to be treated. The platform allows the solution to be applied by gravity flow.

To control the flow of the solution from the tank, one of three methods can be used:

- First, to reduce the flow, raise the tube that lets water into the bowl to the height near the water level in the tank (see Figure 4 - 4). Lowering the tube increases the flow.
- Second, reduce the size of the opening to the bowl in the top of the inlet tube. See Figure 4 - 5. A glass tube can be heated and drawn out. A brass or copper tube can be flattened out.
- Third, small stones or gravel can be placed in the bowl to increase flow. The stones act as weights and force larger amounts of water to flow into the bowl through the tube. Weights may be added or removed to control the rate of flow.

The tank should be checked often to ensure that it always contains chlorine solution. Chlorination is only effective if sufficient chlorine is added. Water should be tested after chlorination to ensure that there is a residual of 0.4 mg/L after 30 minutes of contact time. A color comparator tester is needed to make this test. Several brands of test kits are available on the market. Those using the orthotolidine test, which produces a yellow color when chlorine is present, are most widely used and cheapest.

Although these kits are available in many areas at a low cost, not everyone has access to one. Therefore, the use of chlorinators may be a guessing game that may give poor results. If water is insufficiently chlorinated, the bacteriological quality will not improve. After chlorinating water, make sure that there is a slight chlorine taste and odor in the water. If not, chances are that insufficient quantities of chlorine have been added. The taste of chlorine should not be too strong, however, or it may keep people from using the water.

When chlorine is used in large quantities, the cost of maintaining an effective chlorination system rises. In the long run, the cost of developing a potable well or spring and protecting it from contamination may be lower than chlorination alone.

4.2.4 Chlorine Metering Pump

A chlorine metering pump, also known as a hypochlorite feeding machine, should be installed to feed a chlorine solution into the water line between the well pump and the storage tank. Select a semi-automatic type chlorine-metering pump that feeds chlorine at a constant rate and has a manual adjustment. The machine shall be the manufacturer’s latest approved design, constructed of materials which have proved satisfactory for the type of service required, with all parts arranged so that it is readily accessible for inspection, cleaning, repair, and replacements. Construction shall be simple and practicable in order to secure reliable service. The machine shall be designed to apply up to 5% available chlorine solution under pressures up to a maximum of 125 pounds per square inch (psi) through solution hose or tubing furnished with the machine, to the point of application. See Figure 4 – 6.

4.2.4.1 Dosage

The machine shall be capable of delivering a chlorine solution containing 1% available chlorine in order to provide a chlorine dosage of 0.5 parts per million (ppm) minimum, to 2 ppm maximum, when applied to water at the flow rate of the well pump. With a 5% chlorine solution, the maximum chlorine dosage is 10 ppm.

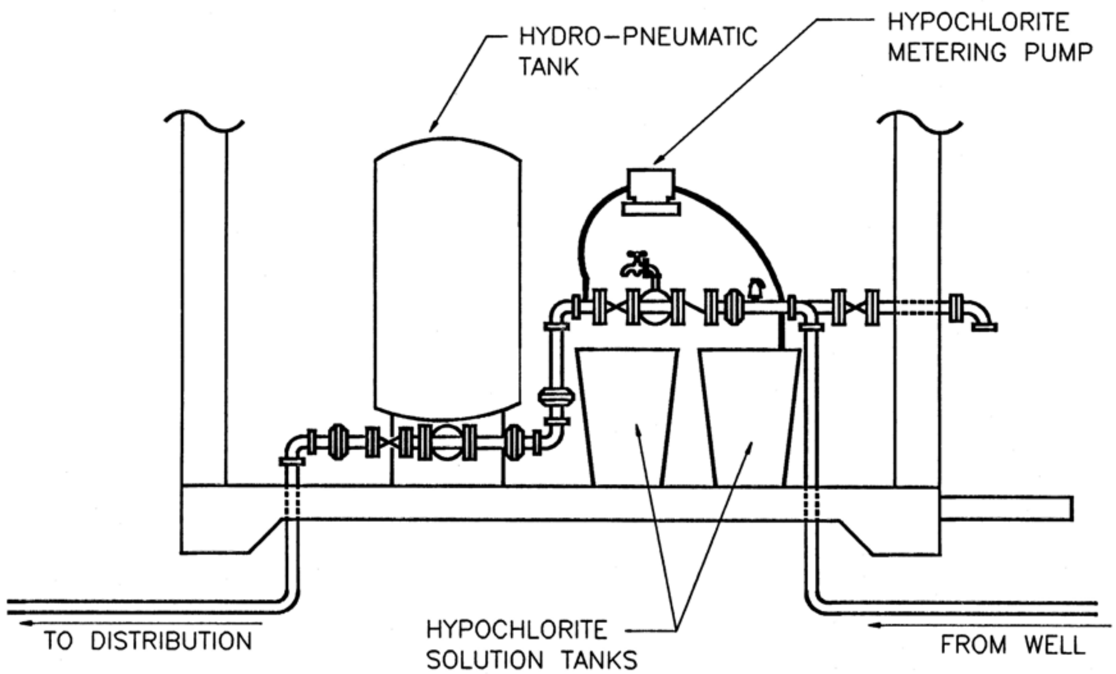


Figure 4 - 6 Typical Installation of Chlorine Metering Pump with Hydro-Pneumatic Tank

4.2.4.2 Controls

The necessary controls shall be provided for the automatic operations of the chlorine-metering pump to correspond with the pumping operation of the well pump. The electrical circuit serving the machine shall be connected in series with an auxiliary contact that is normally open, provided in the motor starter. When the well pump motor is operating, the machine will operate, and when the well pump motor stops, the machine will stop. A device shall be provided to permit manual adjustment of the rate of chlorine solution feed throughout the range of the hypochlorite-feeding machine. The variation in actual feed shall not exceed 10% above or below the set rate.

4.2.4.3 Delivery of Chlorine Solution

The chlorine metering pump assembly shall include chlorine solution storage tanks from which the solution shall be delivered to the point of application by means of displacement or mechanical devices operated by an electric motor. Gages, connections, solution hose or tubing, strainers, valves, and appurtenances necessary for satisfactory operation shall be furnished. Provision shall be made to prevent siphoning of the chlorine solution into the point of chlorine application in case of low pressure or partial vacuum in the water main and also to prevent backflow when the apparatus is not in operation. The machine shall be provided with a sight feed glass for visible inspection to determine whether the chlorine solution is being correctly delivered. The sight glass shall be easily removable for cleaning. Parts subject to contact with chlorine solution shall be made of materials that will not be affected by chlorine in gas or solution form. Tanks shall be of material specified in Section 4.2.4.4 Chlorine Solution Tanks.

4.2.4.4 Chlorine Solution Tanks

Two tanks shall be furnished with the hypochlorite-feeding machine. Each tank shall have a capacity of at least 30 gallons. Tanks shall be of ceramic material, plastic not subject to damage by the chlorine solution, or steel properly coated inside with plastic or lined with rubber or other acceptable material not subject to damage by the chlorine solution.

4.2.4.5 Pumps or Mechanical Devices

Pumps or mechanical devices required for conducting or forcing the chlorine solution into the point of application shall be designed especially for that purpose. The motor shall be designed to operate on 120-volt, 60-cycle, single-phase alternating current and shall conform to the requirements of National Electrical Manufacturers' Association (NEMA MG-I). The unit shall be provided with a type "SO" portable electric cord and a 3-pole polarized grounded type plug. The plug must match the receptacle provided. Pumps may be driven by V-belts or gears, fully guarded. Gears shall operate in oil or shall be provided with other suitable lubricating devices requiring infrequent attention. Rubber diaphragms, if used, shall be reinforced with fabric or other material to insure satisfactory service when in use against water pressure as specified herein. Pumps may be of the diaphragm or plunger type. The reciprocation of the diaphragm or plunger shall be in a straight line. Oscillating cylinders should not be considered. Inlet, discharge, and check valves shall be designed to give positive and efficient operation and to prevent clogging.

4.2.4.6 Chlorine Solution Lines

Rubber hose or plastic tubing specially designed to resist the action of chlorine shall be provided to connect solution tanks with pumps or other devices and to conduct the solution to the point of application. Horizontal runs of the hose or tubing shall be adequately supported. Shut off cocks, as required, shall be provided. The chlorine solution shall be introduced into the water main by means of a hard rubber or plastic injection nozzle or by means of a silver diffuser tube inserted into the main through a corporation cock. The device for introducing the solution into a pressure main shall be constructed in such a way that any accidental breakage of discharge hose or tubing will not cause water to escape from the water service line. The device will allow for disassembling of the unit without leakage from the main.

4.2.4.7 Piping

Piping carrying water shall be of materials as recommended by the manufacturer of the chlorination equipment.

4.2.4.8 Associated Equipment and Spare Parts

The following associated equipment and spare parts shall be obtained and furnished to the local water authority along with the operation and maintenance schedule:

- One extra of each glass, hard rubber, or clear plastic part for the machine;
- An extra supply of gaskets (3 each) to fit all joints for the machine;
- A set of special wrenches, keys, or other special tools needed in the repair, adjustment, or operation of the apparatus;
- Two extra diaphragms for the machine and one extra set of hose clamps, if rubber hose is used; and

- One residual chlorine comparator of a type employing permanent color standards and 26-mm depth sample tubes, with corrosion resistant case, prismatic eye pieces, and chlorine disk reading from 0.10 to 1 ppm in nine steps. One hundred cubic centimeters (cm^3) of orthotolidine solution shall also be furnished.

4.2.5 Tee Chlorinator

A tee chlorinator is an inline system located between the well pump and the water storage tank. Calcium hypochlorite tablets are contained inside the tee, and the water pumped from the well dissolves the tablets as it passes through the tee chlorinator. The operation is simple. The tee chlorinator when installed looks like an inverted T. Valves should be installed on both sides of the chlorinator to cut off flow and pressure for maintenance. After closing the valves on both sides of the chlorinator, open the cap at the top of the chlorinator, and add additional tablets as necessary. Close the top, and open both valves. See Figure 4 - 7 and Figure 4 - 8.

Figure 4 - 7 Tee Chlorinator (1)

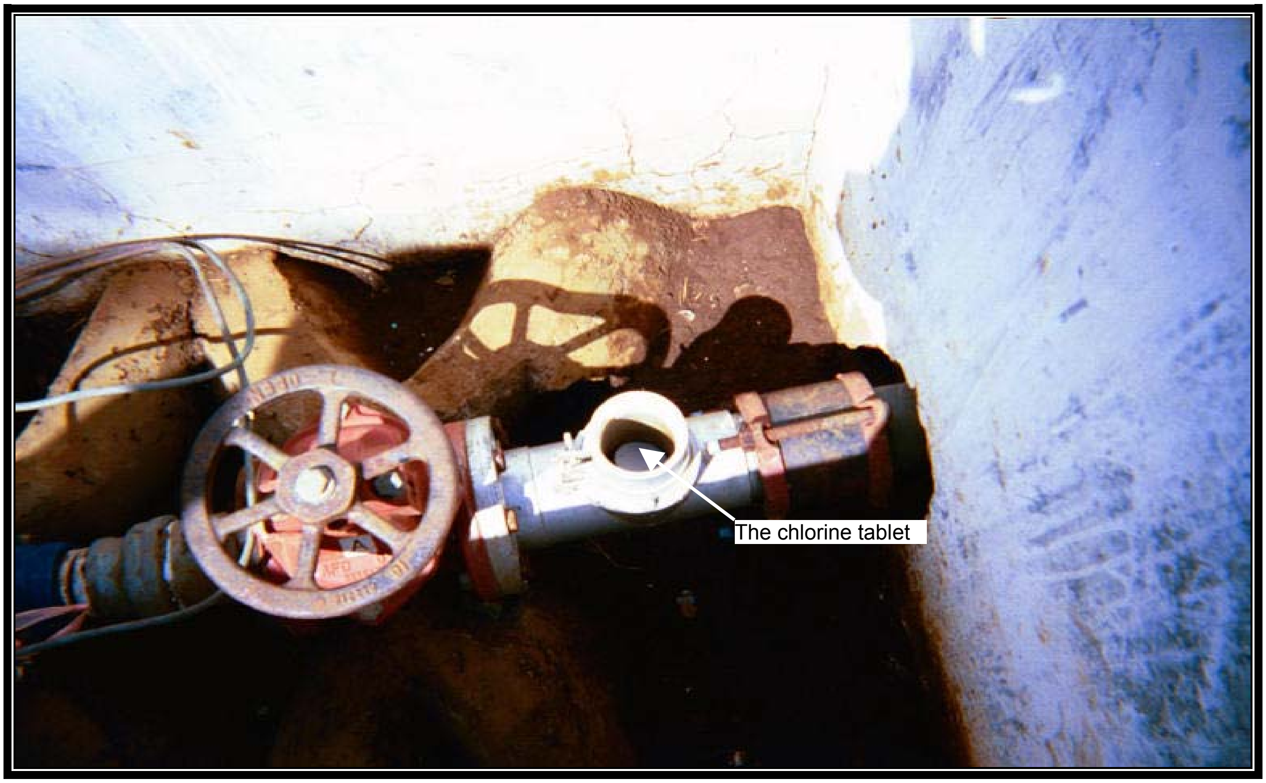


Figure 4 - 8 Tee Chlorinator (2)

4.3 Operation and Maintenance of Chlorine Disinfection Units

When chlorine compounds are used for disinfecting drinking water, the systems that add chlorine to water must be well maintained to provide the correct dosage and prevent disruption in the application of chlorine. This technical note discusses the operation and maintenance of simple disinfection units and describes a maintenance program to follow in order to ensure constant and adequate treatment of water.

For all chemical disinfection units described herein, the most important task is to make sure that sufficient chlorine is available in the water. For successful operation and maintenance, the following steps apply:

- Check each chlorinator periodically. It is very easy to tell when drip and floating bowl chlorinators need additional chlorine. When the solution is low, refill the jar or barrel with a 1% or 2% chlorine solution. At first, it is more difficult to determine when to change the chlorine in pot chlorinators unless the water can be tested. The volume of water and its quality determines how long the chlorine will last. Generally, chlorine powder should be changed at least every week to ten days. Establish a regular schedule for refilling chlorinators.

- When removing a chlorinator to add additional solution or powder, be sure to check that all parts are in good repair. In drip feed and floating bowl chlorinators, carefully inspect hoses and tubes. Rubber can be damaged by chlorine. Hoses must periodically be changed due to reaction with chlorine.

- Check pipes and tubes for clogging, and remove any deposits or sediment that may have built up at the tube openings.

- Determine if the flow of chlorine solution from the feeders is correct. If not, adjust the tube that lets solution into the bowl. Raising the tube reduces the flow, while lowering the tube increases the flow. See Figure 4 - 4 or Figure 4 - 5. Using a clamp on the rubber hose can also control flow.

- Make sure that all supports for the chlorinator are strong. If chlorinators are hung by rope, be sure that the rope is not frayed. Change rope as necessary to prevent chlorinators from falling into wells.

- Store chlorine in a cool, dark place, and be sure that all containers are well sealed. Improperly stored chlorine quickly loses its strength.

- Whenever possible, test the water before and after treatment to determine how much treatment is necessary and whether there is sufficient chlorine residual. Unless the water is tested, there is no real way to determine if treatment is adequate. Insufficient treatment is no more useful than no treatment at all. If testing is impossible, be sure that chlorine is always changed on schedule. Otherwise, water quality cannot be ensured.

Simple chlorination can be used to treat small community water supplies. The cost of a chlorination system is relatively low, if very large quantities of chlorine are not required. Simple pot chlorinators and solution feed systems are built with local materials and require little skilled labor. Chlorination systems are best used where water quality and chlorine levels can be tested periodically to ensure good water quality. Where testing is not possible, alternatives to chlorination should be sought.

4.4 Summary

In Latin America, all surface water is considered to be contaminated. Groundwater is often free of disease-causing bacteria. Regardless of the source of the water, chlorination is recommended as the minimum level of water treatment for all systems that include water storage tanks. Several methods of chlorination are described in this section. Pot chlorinators, drip feed chlorinators and floating bowl chlorinators are other methods of disinfection for small rural community water systems. These units are placed in or above water storage tanks or hand dug wells. Chlorine metering pumps are commonly used to disinfect small rural community water supply systems. They are placed in the well house, wired to operate simultaneously with the well pump so that they are energized with the well pump. Tee chlorinators are in line units located on the water line between the well pump and the water storage tank.

SECTION 5

PUMPS AND ASSOCIATED EQUIPMENT

EXECUTIVE SUMMARY

This section covers pumps and related equipment that serve the purpose of moving water from the source to the point of use. The various types of pumps are discussed include hand pumps, windmills, hydraulic rams, centrifugal pumps, jet pumps, vertical turbines, and submersibles. Hand pumps and submersibles will be the focus due to their frequent use for the engineer exercises. Pump selection should consider specific site conditions including the availability of electric power, the depth to water, the quantity of water needed, pressures, required, and the location and conditions of the point of use. These factors will direct the engineer to a specific pump that best suits the project. Electric submersible pumps and hand pumps are the most commonly used pumps in the HCA water wells installed during troop engineering exercises. Dempster Mark III hand pumps are preferred when no power is available. Pumps commonly used in domestic water systems are centrifugal, positive displacement (piston), or ram. When only animal or wind power is available, positive displacement pumps are the best choice. Hydraulic ram pumps are water driven. These pumps are simple and economical to operate and maintain. The WHO recommends that provisions be made for a minimum of 40 L/person/day of water if a communal distribution point is used. Where water must be hauled to the distribution point, 15 L/person/day should be provided. For water piped to the home, 100 L/person/day is recommended.

The following items are highlighted in this section:

- For wells with electric pumps installed, pumping time should not exceed 16 hours per day.
- For six-inch diameter wells, the installed pump should be no larger than four inches in diameter.
- Testing for windmill design will be required well in advance of the exercise.
- It is highly recommended that the installer purchase the submersible pumps in the country after the well pumping test is conducted. However, electric pumps should be purchased only if the community can accommodate its usage.

5.1 Introduction

Pump selection, pump installation, pump performance curves, pump requirements, pump comparison, protection of pumps and electrical components are discussed in this section. An example of design for a submersible well pump system is given at the end of the section.

Electric submersible and Dempster Mark II and Mark III hand pumps are the most commonly used pumps in water wells installed during the New Horizons troop engineering exercises. It is highly recommended that the installer purchase the submersible pumps in the country after the well pumping test is conducted. It is impossible to determine the amount of water a well will yield before it is drilled, developed and tested. The specific pump required for the application must be selected after the well testing is complete. Repair parts and service will also be more likely available if the electric pump is purchased within the host country.

Electric pumps should be purchased only if the community can accommodate its usage (funds for power, repair, etc.). Many communities have problems with theft, lack of funds to pay for the power, or power surges that can damage pump motors. Often, submersible pump ownership is considered a 'status symbol', and some communities will ask for a submersible pump even if they do not have the resources to operate and maintain it. The designer should consult with civil affairs officers and community leaders to ensure the population will have access the water.

Dempster Mark III and Mark II hand pumps are often installed in HCA wells and are available in Latin America. Many non-government organizations (NGOs) and host nation water authorities use this type hand pump for their domestic wells. They are durable and repair parts are obtainable in country. These pumps are typically procured in the United States (U.S.) and shipped over for the exercise. A kit of repair parts, an installation manual, and an installation tool kit are recommended for each pump installed. Mecate Rope Pumps are also good hand pumps to use. These are manufactured in Nicaragua, and are available in Latin America. Hand pumps are recommended for communities without a source of electric power.

For wells with electric pumps installed, pumping time per day should not exceed 16 hours per day. Pumping a well more than 16 hours per day (hr/day) can cause 'aquifer stress' which can permanently damage the aquifer and render a well useless.

Regardless of submersible pump manufacturer's recommendations, for six-inch diameter wells, the installed pump should be no larger than four inches in diameter. Some manufacturers suggest using a submersible pump with a diameter greater than five inches for six-inch wells. However, this is not recommended. In these cases, there is not enough clearance for pump wires, water flow, or misalignments. The maximum amount of yield possible from most four-inch diameter submersible pumps (i.e. 6-inch wells) is about 100 gallons per minute (gpm).

If windmills will be used, the proper testing for windmill design will be required well in advance of the exercise. The pump and motor must be easily accessible for repair, replacement, operation, and preventive maintenance. The pump and motor should be accessible in all weather conditions.

5.2 Selecting Pumps

The preferred method of delivering water from the source to the point of use is by gravity flow, because no external power source or mechanized apparatus is required. Water sources are often lower in elevation than the point of storage or use. The rate of flow must be increased, or the water must be pumped to compensate for the differences in elevation. See Figure 5 - 1.

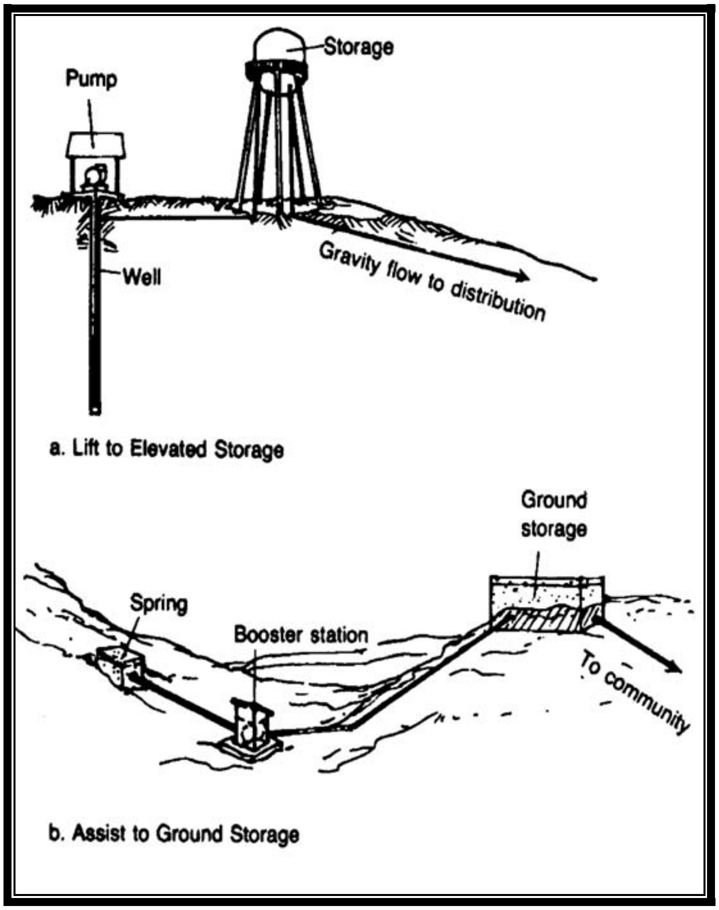


Figure 5 - 1 Situations Requiring Pumps

5.3 Types of Pumps

Electric submersible pumps and hand pumps are the most commonly used pumps in the HCA water wells installed during troop engineering exercises. Dempster Mark III hand pumps are preferred when no power is available. Pumps commonly used in domestic water systems are centrifugal, positive displacement (piston), or ram. The pumps are illustrated in Figures 5 - 2, 5 - 3, and 5 - 4.

The type of pump selected depends on the volume of water required, pumping head, and type of power available. Centrifugal pumps include single stage suction, jet, submersible, and line shaft turbine pumps. These pumps require electric motors or internal combustion engines for power. Submersible pumps are among the most common installed during troop engineering exercises and are most commonly purchased within the country. When only animal or wind power is available, positive displacement pumps are the best choice. Hydraulic ram pumps are water driven. These pumps are simple and economical to operate and maintain.

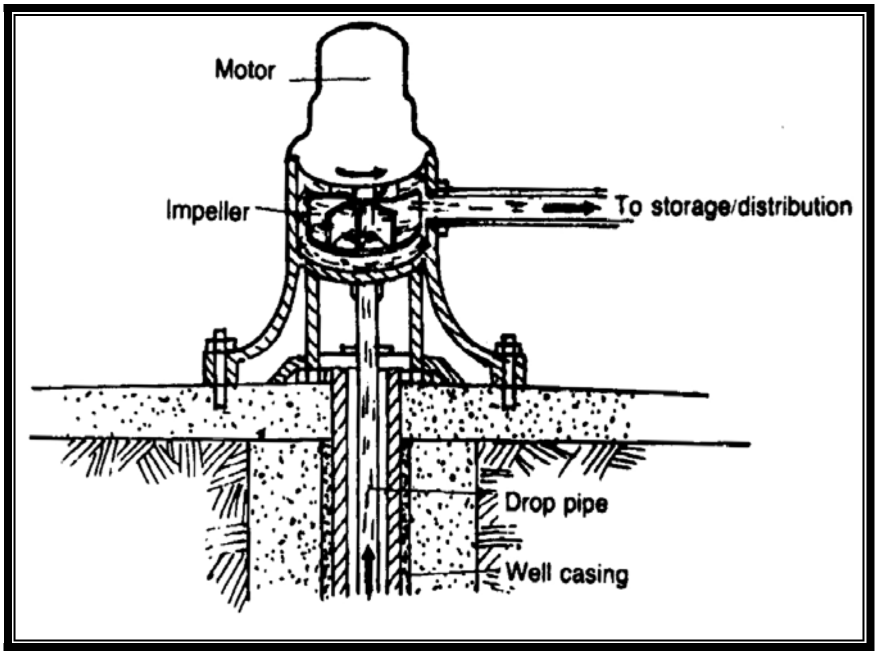


Figure 5 - 2 Centrifugal Pump

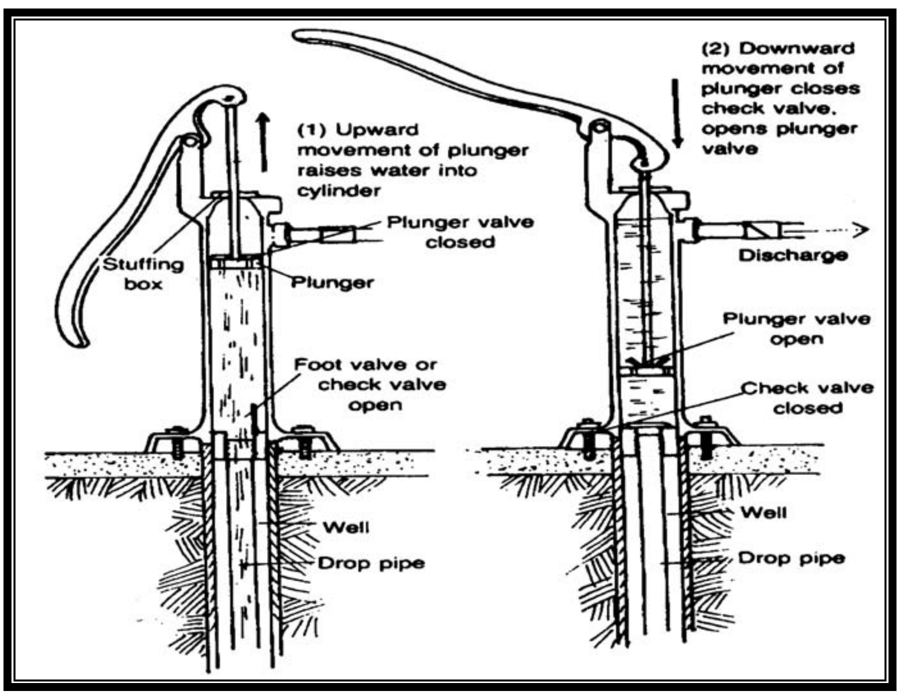


Figure 5 - 3 Positive Displacement Pump

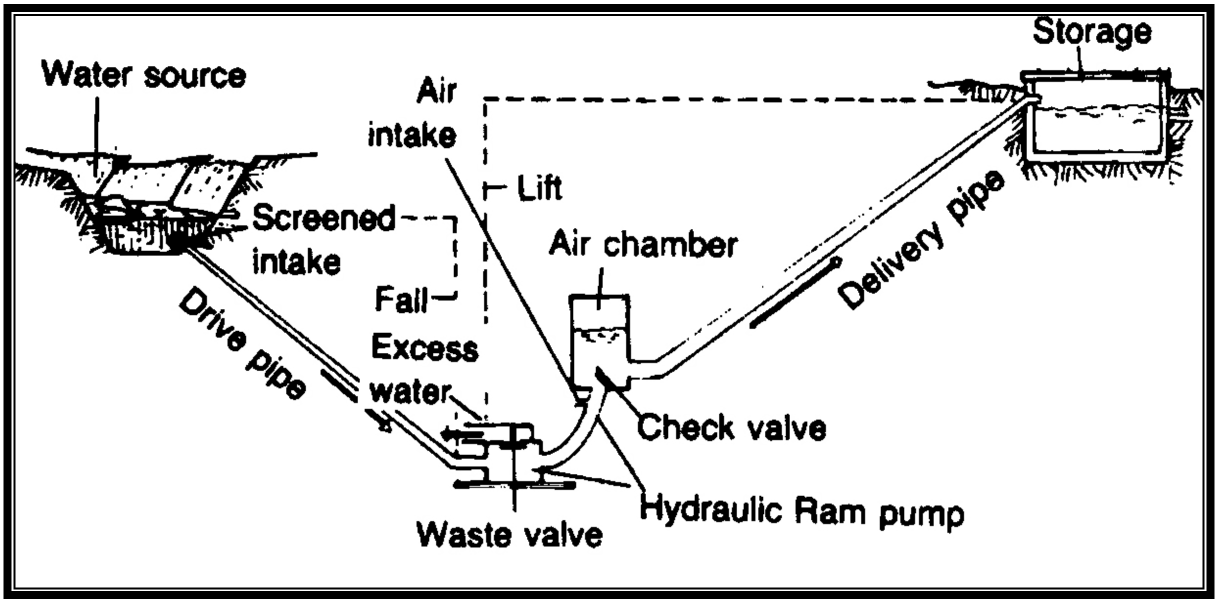


Figure 5 - 4 Hydraulic Ram

5.4 Pump Categories and Types

Pumps can be divided into two categories based on their power source.

- **Category 1 -** pumps powered by animals, humans, wind or water.
  These pumps usually produce low volumes of water at or near the source, including bucket, hydraulic ram pumps, and positive displacement pumps.

- **Category 2** - pumps powered by electric motors or external combustion motors.
  These pumps include single stage suction, jet pumps, submersible and line shaft turbine pumps. They produce medium to high quantities of water compared to Category 1 pumps.

Within categories, there is a distinction between shallow and deep well pumps. See Figure 5 - 5. Shallow well pumps are those that can pump from a water surface depth of 20 feet (7 m) or less, which is the maximum practical suction lift at sea level. Deep well pumps can pump from much greater depths depending on the pump design. Note that shallow dug wells are rarely installed as part of HCA missions.

- Shallow Well Pumping - Although shallow wells (<100 ft deep) are not recommended for a HCA well drilling exercise, there may be occasions when wells drilled deeper than 100 ft have water levels of less than 20 feet below surface level. These pumps must be located within 7 m vertically of the water surface when at sea level and must be closer to the water at higher elevations due to the reduced atmospheric pressure. For every 300 m of elevation above sea level, reduce the distance of the pump to the water by 25 cm. The actual suction capability varies with the pump being considered. Shallow well pumps include surface mounted, positive displacement, piston pumps and centrifugal pumps. Centrifugal pumps include shallow well jets, turbines and straight centrifugal pumps. The positive displacement pump may be selected for relatively high heads and low flows; however, centrifugal pumps are more readily available.

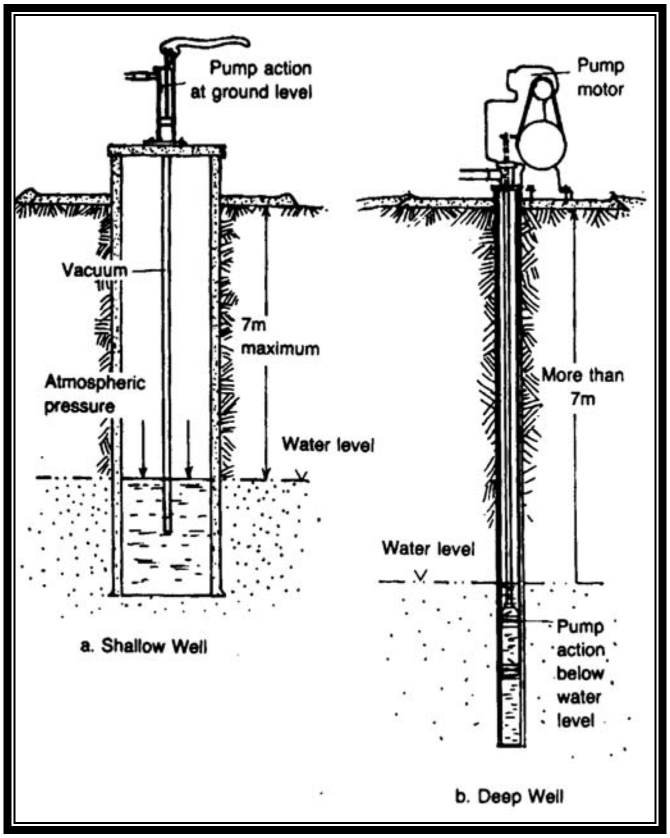


Figure 5 - 5 Shallow and Deep Well Pumps

- Deep Well Pumping - Deep well pumps can draw water from over 7 m deep. Types of deep well pumps include a submerged piston pump shown in Figure 5 - 6, submersible turbine, line shaft vertical turbine, and jet action pumps, shown in Figure 5 - 7. Piston pumps can theoretically pump from great depths. However, due to the weight of the sucker rods combined with other limitations, the maximum pumping depth is limited to 300 m. Due to recommended drill depth limits by the U.S. military during troop engineering exercises, water levels will be much shallower than 300 m.

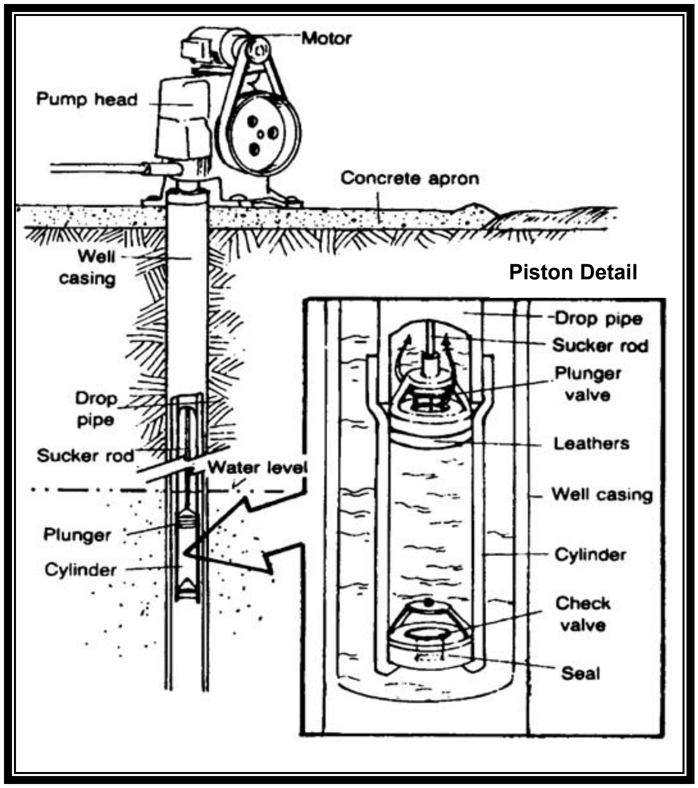


Figure 5 - 6 Motor Driven Positive Displacement Pump (Submerged Piston)

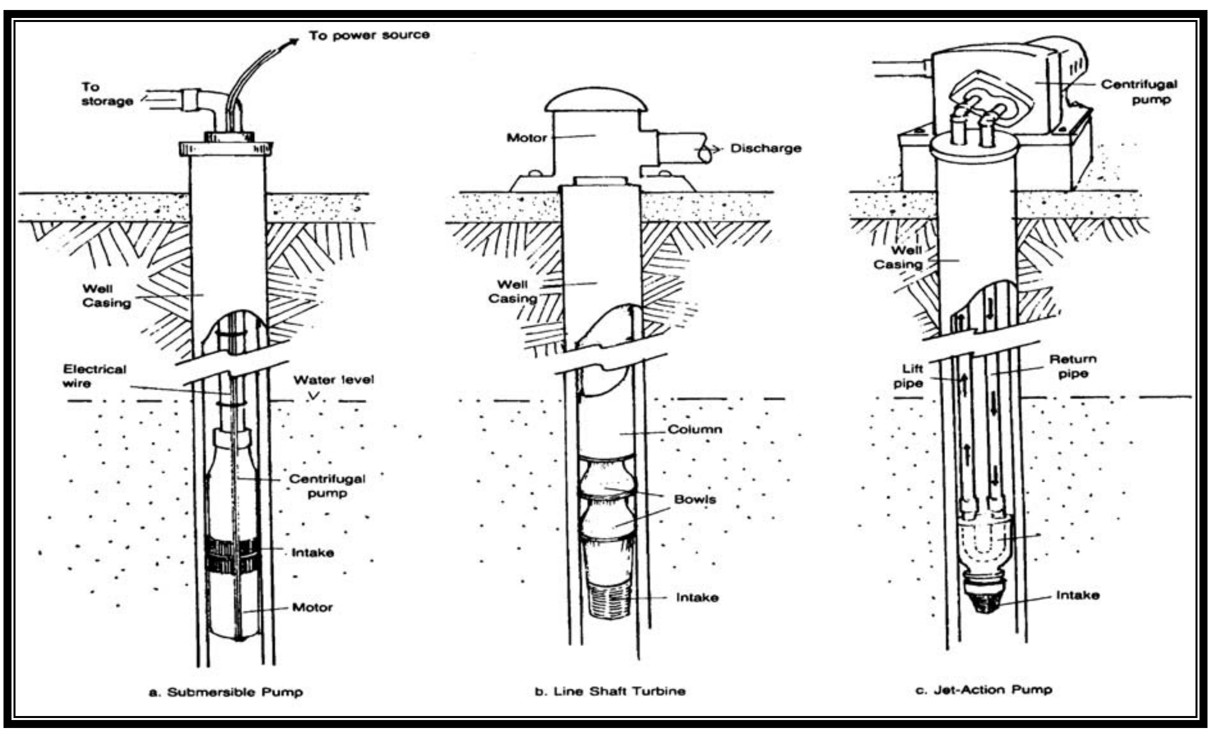


Figure 5 - 7 Examples of Deep Well Pumps

A description of the various pump types follows.

5.4.1 Bucket Pump

This type of pump may be used for large diameter hand dug wells, where the depth to water is shallow, and when low quantities of water are needed or available. Several variations exist:

- **Rope and Bucket.** In shallow wells, it is common to drop a bucket tied to a rope directly into the well. In deeper wells, more leverage is required, or animal power may be used to raise the water. This method is undesirable from a public health viewpoint as contamination can be easily introduced into the well by careless placement of the rope and/or bucket. For this reason, rope and bucket should ***not*** be considered unless other alternatives are not available. See Figure 5 - 8 (a. single bucket).

- **Continuous-Belt Bucket Pump.** This variation is much more sanitary than a rope and bucket but is more expensive to install. Essentially, this method involves attaching small buckets to a continuous loop as shown in Figure 5 - 8 (b. continuous belt bucket pump). The Mecate Rope Pump (see Appendix F) is gaining popularity in Latin America as an alternate to traditional hand pumps, such as Dempster Mark II and Mark III hand pumps. It was developed in Nicaragua in the 1990s. The principal elements are a pulley wheel, a rope with pistons attached, a pipe that enters the well, and a guidance device for the rope at the base of the pipe. As the crankshaft is turned, the rope drags the pistons up the pipe, traps the water in the pipe between the pistons, and ejects the water at the surface. The pump functions well at water depths up to 50 m. This is a low cost, low maintenance hand pump. One disadvantage is the potential for contamination. As the rope goes from above the ground surface down into the well and back up again, it can contaminate the water source.

5.4.2 Hydraulic Ram

A hydraulic ram has very few moving parts and is very economical to operate and maintain. Hydraulic rams may be used singly or in tandem depending on the amount of water available and/or required. The water is raised to a higher elevation by the force of falling water that creates a drive force within the ram by compressing air. This action in turn pushes a small amount of the falling water to a higher elevation. See Figure 5 - 4. This type pump is not used for wells; it is for surface water impoundments.

Most rams require a flow of at least 12 liters per minute (L/min) and a fall of 50 centimeters (cm) in order to work properly. The essential elements of the system include a source at a higher elevation than the ram, a drive pipe, ram, delivery pipe and storage. The water used to drive the ram may be from a different source than the water to be pumped; however, two sources create a potential for cross-contamination. Since only a portion of the water delivered to a ram is pumped to a higher elevation, the source must produce several times as much water as is needed. The water must be free of trash and sand, because they can plug the pump. If acceptable conditions exist, along with a sufficient head, then a hydraulic ram is a good choice. A hydraulic ram requires no external power source and can pump 24 hr/day with very little maintenance.

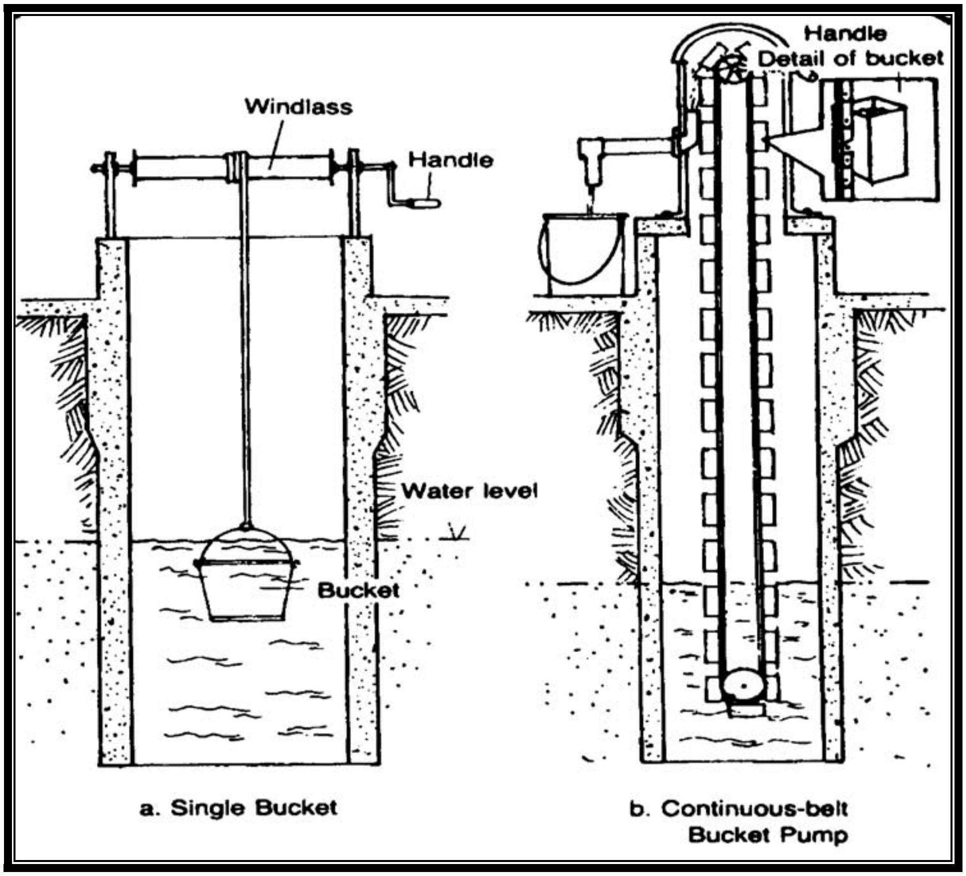


Figure 5 - 8 Bucket Systems in Shallow Wells

5.4.3 Positive Displacement

The positive displacement pump displaces an amount of water equal to the distance the piston travels. See Figure 5 - 6. Double acting pumps are available. Positive displacement pumps are made of a cylinder and a piston that moves on an upward/downward or forward/ backward stroke and tend to be more efficient. The cylinder may be located above or below the water level. When the cylinder is above water, suction is required to lift the water to the piston. This type of pump requires “priming” and is less desirable than a pump with the cylinder below the water level. Priming a pump can cause contamination of a well. The cylinder can be driven by a variety of power sources including a hand pump, windmill, or motor. The amount of water which can be produced is limited by the suction lift, if the cylinder is above the water level; the diameter of the piston; the length the piston travels; and the number of times the piston is moved in a given time period. When the cylinder is located in the water, a sucker rod, usually made of steel, is required to connect the drive mechanism to the cylinder. Due to the weight of the steel sucker rod, a pumping depth of 60 to 80 m for a hand pump should be considered maximum. Positive displacement pumps are the pumps of choice when only hand or wind energy is available, or if motors are available, and great pumping depths and low flow requirements are encountered. If there is adequate power for a motor-driven pump, positive displacement pumps can draw water from depths exceeding 300 m. Positive displacement pumps can be used in small diameter wells. Select a small diameter cylinder, or use the well casing itself for the drop pipe, when the cylinder is built into the pump.

5.4.4 Centrifugal Pumps

Centrifugal pumps include single stage suction, jet, submersible, and line shaft turbine pumps. Submersible and line shaft turbine pumps are a special type of centrifugal pump and are discussed separately. Single stage centrifugal pumps are commonly used for pumping water from reservoirs or tanks, but may also be used for small capacity wells. The centrifugal pump is usually electrically driven, but is available with engine drives, and uses the centrifugal force of a spinning impeller to pump water. They are used almost exclusively in the U.S. for rural domestic water supplies from shallow wells and when combined with the jet-action device, they may be used in deep well applications. These pumps are manufactured in a great variety of sizes and are available in both vertical and horizontal styles. Their advantages include the ease of installation and maintenance, their availability, and their usefulness in a wide variety of applications. Centrifugal pumps are available in the self-priming style that may be useful for reservoir pumping applications. A disadvantage is that they have limited use as well pumps and are only considered for small capacity well applications.

5.4.5 Line Shaft Vertical Turbine

Line Shaft Vertical Turbine Pumps have the motor at the surface with a drive shaft connecting the motor to the pump. The deeper the well, the more shaft guides are required along the drive shaft and the greater the possibility of guide failure. In addition, the shaft needs to be straight and plumb. This requires a straight well bore hole. Since it is extremely difficult to keep deep wells plumb, the pumping depth is often limited. For this reason, practical pumping depths in small diameter wells, 12 cm to 24 cm, are usually limited to no more than 35 m. Large diameter wells, 30 cm and larger in diameter, can be pumped at much greater depths. Failing guides are still a problem as is the possibility shaft breakage. These pumps are capable of pumping high volumes and at high heads (pressure) by adding more pump bowls. See Figure 5 - 7.

5.4.6 Submersible Turbine Pumps

Submersible Turbine Pumps have the advantage of being usable in less plumb wells and can usually be set at greater depths. Since the sealed electric motor is below the pump, the whole unit must be pulled for repairs. Installation is not complicated, because there are no moving parts connecting a motor to the pump. These types of pumps are commonly used for wells installed during engineer exercises. Operation and maintenance problems are reduced, because there are fewer moving parts. These pumps can produce water from great depths. With increasing depth, the motor is larger and the electric cable to the motor. Installing these type pumps can become very expensive since special electric cable, capable of being operated in water, is required. Also, 240 volts and/or three-phase power may be necessary. For these reasons, 150 m should be considered the maximum pump depth. At this depth, special pump pulling equipment would be required. If the electrical service is intermittent, or only available during evening hours, an electrically powered pump should not be used. Approximately 100 gpm is the maximum amount of water that can be produced from a 4-inch submersible pump. A pump producing this amount of water is the maximum size that is recommended for installation in a 6-inch well. See Figure 5 - 7. Table 5 - 1 offers a comparison of different types of pumps according to a variety of factors.

Table 5 - 1 Pump Comparison

	Wind, Water, Animal Powered					Electric, Fossil Fuel Powered			
	Rope and Continuous Bucket	Hydraulic Ram	Positive Displacement			Straight Centrifugal	Centrifugal Jet	Submersible	Line Shaft Vertical Turbine
			Hand	Wind	Motor				
Capacity (L/min)	15 to 70	N/A	10 to 50	0 to 100	12 to 150	Very wide range, almost unlimited	18 to 300	40 to 240 and higher	120 to 360 and much higher
Lift from water to pump (m)	1 to 30	N/A	N/A	Medium to high 8 to 250	Low to high 8 to 500	Low, less than 8	Low to medium 8 to 25	N/A	Medium
Lift from pump to higher level (m)	Normally none	N/A	0 to 3 Normal	0 to 3 Normal	Limited by strength of pipe	Wide range 6 to 500	Usually 6 to 100	30 to 400 and higher	5 to 500
Diameter well required (cm)	Large 100	Not used with wells, can be used with surface impoundments	6	6	6	6, can also be used with surface water impoundments	12 with jet in well	12	12
Efficiency	Low	Low	Low 25 to 60%	Low 25 to 60%	40 to 60%	50 to 85%	40 to 60%	65 to 80%	65 to 80%
Relative cost	Low to Reasonable	Reasonable	Reasonable	Reasonable to high	Reasonable	Reasonable	Reasonable	Reasonable but high at greater depths	Higher
Operation and Maintenance	Very simple	Simple	Simple, needs occasional maintenance	Simple, needs occasional maintenance	Simple, needs attention	Simple, needs attention	Simple, needs attention	Simple, needs attention	More difficult, needs constant attention
Advantages	Easily understood, very simple	Simple, few moving parts	Easy to understand, low cost	N/A	Easy to repair or replace	Easy to repair or replace	Easy to repair or replace	Pump and motor in well less subject to vandalism	Can be operated by alternate power sources, high volume
Disadvantages	Limited use, low efficiency	Needs constant flow of water	Low efficiency, requires some maintenance	Dependent on wind	Needs attention	Requires attention for bearing lubrication	Requires attention	Difficult to pull, needs special electrical cable for wells	Difficult to repair if bearings fail

N/A – not applicable

5.5 Determine Pumping Requirements

Before pumping requirements can be determined, a water source must be identified, the amount of water required must be estimated (based on the population to be served), and the system type must be selected. Well yield will also effect pumping requirements.

The WHO recommends that provisions be made for a minimum of 40 L/person/day of water if a communal distribution point is used. Where water must be hauled to the distribution point, 15 L/person/day should be provided. For water piped to the home, 100 L/person/day or more is desirable. In simpler terms, the amount of water that is used decreases with increasing distance from the water source/tap.

The next most important factor in determining pumping requirements is the pumping head (total dynamic head [TDH]) or pressure. The pumping head is determined by the difference in height between the pump and the highest point in the system (the static head) plus the head needed to overcome friction in the pipe (the friction head). The highest point in the system is usually the water surface elevation in the storage tank. Part of the head may be fixed, as in the case of the location of the pump and the storage tank, and part may vary depending on the difference in flow or pipe size. Pipe size and flow are the primary variables in designing a pumping system. Be sure to include the friction loss (head loss) of any valves, bends, and meters.

Once a water source and system type have been selected, then quantity, pumping distance, and elevation of storage can be measured or calculated. Once these are known and flow is estimated, a pipe diameter can be selected. The information is then used to determine pump size based on flow and pressure (TDH) requirements. Appendix G provides example scenarios for determining pumping requirements.

5.6 Installing Hand Pumps

Hand pumps may be used in wells with static water levels less than approximately 230 feet below ground surface. With the cylinder in the water, the pump does not lose its prime, and the pump leathers do not dry out. In shallow well pumps, the cylinder is in the pump body above ground.

Dempster Mark III and Mark II hand pumps are the most commonly used in Latin America during troop engineering exercise. These hand pumps and parts, manufactured by Dempster Industries, are obtainable in Latin America and are commonly used by NGOs and host nation water authorities.

A hand pump system consists of a hand pump stand, drop pipe, pump rod or sucker rod for deep wells, and a pump cylinder. For shallow wells, the cylinder is part of the hand pump stand. Some hand pump stands lift water to a spout or force it to a higher elevation or to a point located away from the well. Figure 5 - 9 shows a shallow and a deep well hand pump. This technical note only describes the basic steps in hand pump installation and pumps should be installed according to the manufacturer’s directions.

For all installations, it is important that the water source not be contaminated. The top of the well should be fully enclosed with a concrete well slab placed around the well. Only materials that are clean and made for use in potable water supplies should be used.

While preparing a materials list, careful measurements must be made to ensure that sufficient material is available. Prior to cutting material for assembly, good development practices require careful measurements. It is necessary to have the proper tools on site when installation begins. Table 5 - 2 describes the materials and tools needed for a typical hand pump installation.

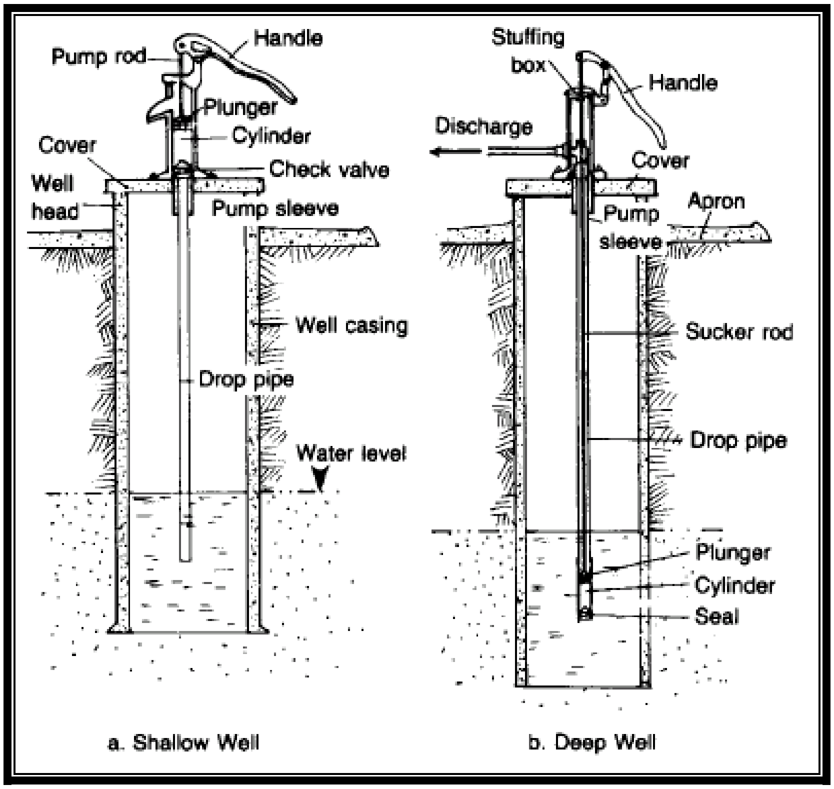


Figure 5 - 9 Hand Pump Systems

As in all projects, careful pre-planning will help assure that installation involves a minimum of wasted time. A sample work plan is shown in Table 5 - 3.

This plan can be used to estimate the time needed to complete the job and to decide when materials and tools should be available. Figure 5 - 10 shows the installation of the drop pipe and cylinder using a tripod. Figure 5 - 11 shows the detail of installing a pump sleeve, and Figure 5 -12 shows details of a typical hand pump installation.

After the pump installation is complete, but prior to bolting the pump stand to the mounting flange, the well should be pumped until the water is clear. A strong chlorine solution should be used to disinfect the well. A well may be disinfected by raising the pump assembly from the flange and pouring the solution down the well. After 12 to 24 hours, the well can be pumped out, and the water can be used for disinfection procedures.

Table 5 - 2 Sample Materials List for Hand Pump Installation

Item	Description	Quantity	Estimated Cost
Labor	Foreman Laborers	1 2	______
Supplies	32 mm galvanized steel pipe with coupling 10 mm galvanized steel pump rod Well cylinder Hand pump stand with handle Pump mounting flange Packing material Small can of grease Cutting oil Chlorine solution	_ m: (to reach desired well depth) _ m: (to reach desired well depth) _ m: (one for each joint) ______ ______ ______ ______ ______	______ ______ ______ ______ ______ ______ ______ ______
Tools	Portable pipe vise Large pipe wrenches Crescent wrenches (adjustable wrenches) Pliers Hacksaw with spare blades Pipe cutter Pipe threader, 10 mm and 32 mm Measuring tape, 3 m and 12 m Pipe holder Rope and pulley Tripod for lowering pipe Plumb bob and 50 m of line	______ ______ ______ ______ ______ ______ ______ ______ ______ ______ ______	______ ______ ______ ______ ______ ______ ______ ______ ______ ______ ______
	Total Estimated Cost **$**		

Note: Either the foreman or the laborers must have some experience in cutting and threading pipe.

Table 5 - 3 Sample Work Plan for Installing a Hand Pump

Time Estimate	Day	Task	Tools/Materials
1 hour	1	Deliver materials to site and unload	See Table 5-2
1 hour	1	Set up tripod	Tripod, wrenches
1 hour	1	Cut and thread pipe and pump rod as measured	Pipe vise, cutter, threader, cutting oil
3 hours	1	Attach pump rod and cylinder then lower into well; add pipe and rod as required until desired depth is reached	Pipe, pump rod, pipe holder, and pipe wrenches
1 hour	1	Attach pump mounting flange to well casing, screw pipe into bushing into base of pump stand	Pump mounting flange, pipe busing, pump stand wrenches
1 hour	1	Check pump packing and packing nut; lubricate pump bearing points; work pump until water is clear; add chlorine solution to well and let stand overnight	Packing material, grease, wrenches, and chlorine solution
2 hours	2	Pump well until no chlorine solution remains; attach stand to flange	N/A

Note: A foreman and two laborers are required for these tasks.

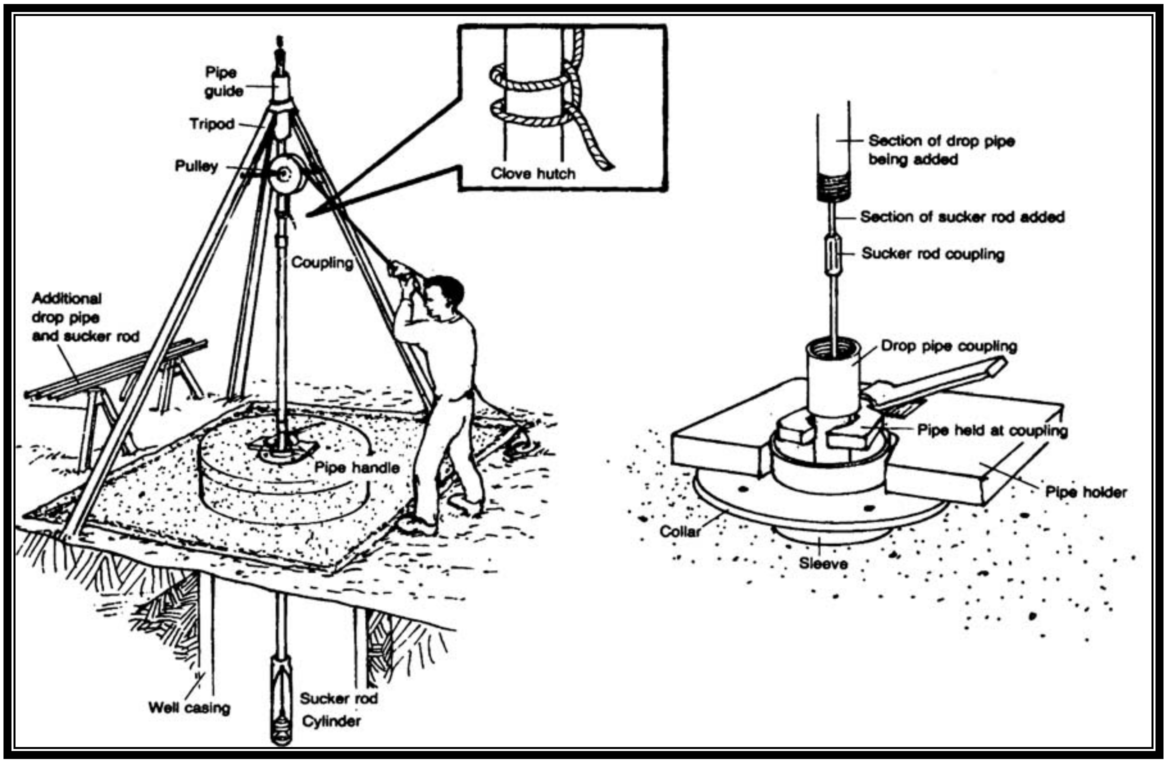


Figure 5 - 10 Installation of Drop Pipe and Cylinder

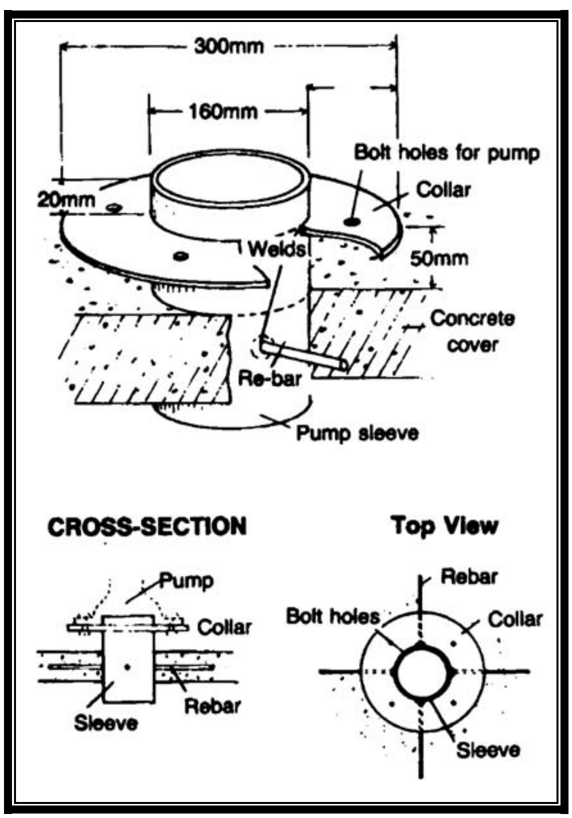


Figure 5 - 11 Installing Pump Sleeve

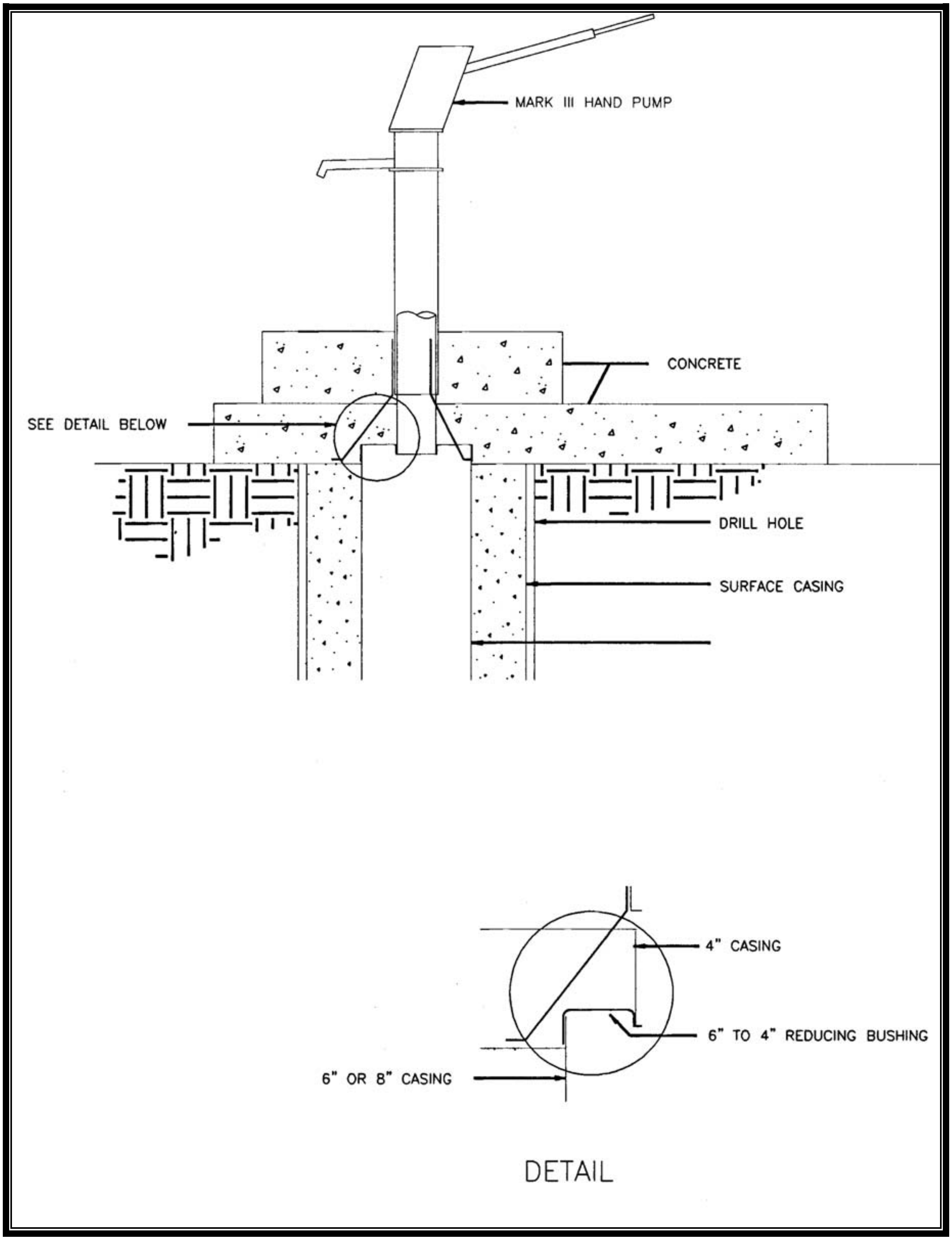


Figure 5 - 12 Typical Hand Pump Installation

5.7 Installing Mechanical Pumps

Installing mechanical pumps for community water systems involve several considerations including:

- ✓ Protecting the pump and motor from vandalism and weather
- ✓ Ensuring accessibility for operation, maintenance and replacement
- ✓ Minimizing potential contamination of the water supply
- ✓ Proper sizing and protection of electrical components
- ✓ Providing pump controls and metering.

Both pump and motor should be protected from weather extremes. In areas where freezing occurs, supplemental heat may be needed. Usually this means that a pump house is required. Even if the pump is in the well and an underground discharge is used, pump controls are needed, and the water should be metered. Meters should be installed in the pump house, if available, or in a concrete meter vault. Pumps should not be placed in pits due to the risk of flooding. See Figure 5 - 13.

Earth can be mounded around a pump house for insulation as long as the floor of the pump house can be drained to ground level by gravity flow.

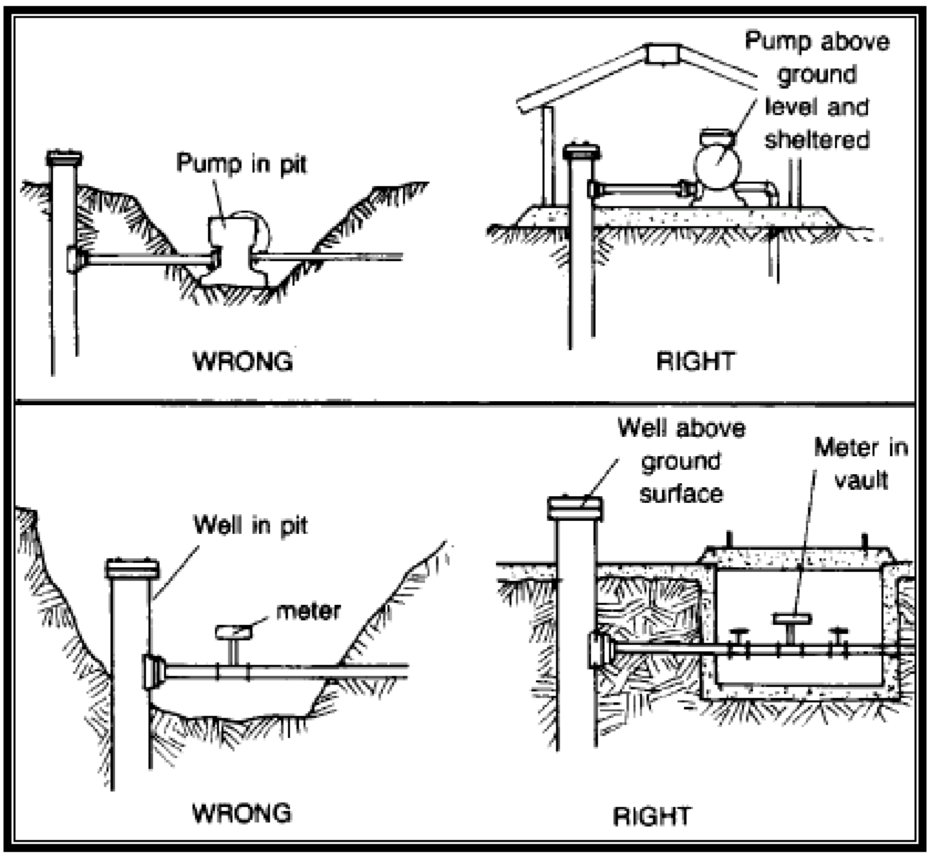


Figure 5 - 13 Locating Pumps and Wells

If the well is located inside the pump house, roof access will be needed, so the drop pipe and/or the pump in the well can be removed. See Figure 5 - 14.

For small pump houses, the entire roof can be removed. Care must be taken to locate and size the doors to ensure the pump and other equipment can be removed for repair or replacement. A vent is required to minimize excess moisture. For deep wells, a method to hoist the pipe and pump may have to be incorporated into the design.

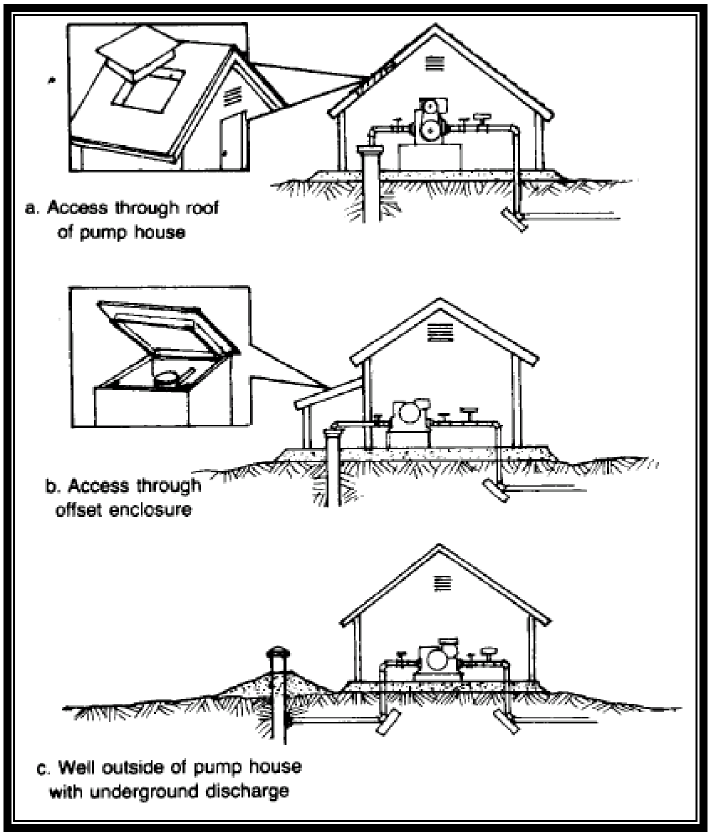


Figure 5 - 14 Providing Access to Well for Pump Removal

5.7.1 Sizing and Protection of Electrical Components

The electric wires within the pump house should be enclosed in flexible cable or conduit. Caution should be exercised in using the correct size wire and fuses. Table 5 - 4 shows the correct sizes for motor of varying horsepower. The electric meter should be located as close to the pump as possible, preferably along with a main circuit breaker on the outside of the pump house.

Although lightning surges are not common, they occasionally cause damage to pump motors. To protect against these surges, a lightning arrester should be installed either at the service entrance or at the switchbox. Care must be taken to install adequate grounding. Driving a ground-rod into the earth, with a copper wire connection to the entrance, may ground the electrical components and keep them from burning out.

5.7.2 Pump Controls

Pump motors must be turned on and off in accordance with water needs. A pump may be operated by a person manually controlling a switch, by a clock, by pressure differences, or by high/low probes in the water. These controls are used to maintain the water level in a storage tank, to maintain the pressure in a system, and/or to protect a pump from low water levels in a well or low flows, which can cause a pump to burn out.

Table 5 - 4 Wire and Fuse Table (from Service Entrance to Pump Motor or Control Box)

H.P †	VOLTS	FULL LOAD (amps)	*MAX. FUSE SIZE (amps)	**Minimum Wire Size of Rubber Insulated Copper Wire-A.W.G††									
				Length Wire from Motor to Meter of Distribution Point-Meters									
				0-15	15-30	30-45	45-60	60-75	75-90	90-105	105-120	120-135	135-150
1/6	115	3.0	15	14	14	14	14	14	14	14	12	12	12
1/6	230	1.5	15	14	14	14	14	14	14	14	14	14	14
1/4	115	4.0	15	14	14	14	14	14	12	12	12	12	10
1/4	230	2.0	15	14	14	14	14	14	14	14	14	14	14
1/3	115	5.0	15	14	14	14	14	12	12	12	10	10	10
1/3	230	2.5	15	14	14	14	14	14	14	14	14	14	14
1/2	115	7.2	25	14	14	14	12	12	10	10	10	9	9
1/2	230	3.6	15	14	14	14	14	14	14	14	14	14	14
2/4	115	9.2	30	14	14	12	12	10	10	9	9	8	8
2/4	230	4.6	15	14	14	14	14	14	14	14	14	14	12
1	115	12.0	40	14	12	12	10	9	9	8	7	7	6
1	230	6.0	20	14	14	14	14	14	14	14	12	12	12
1 ½	115	16.0	50	14	12	10	9	8	7	7	6	5	5
1 ½	230	8.0	25	14	14	14	14	14	12	12	12	10	10
2	115	20.0	60	14	12	10	8	7	6	6	5	5	4
2	230	10.0	30	14	14	14	14	12	12	12	10	10	10
3	115	29.0	90	12	10	8	7	6	5	4	4	3	3
3	230	14.5	45	14	14	14	12	12	10	10	9	9	8
5	115	46.0	150	10	8	6	5	4	3	2	2	1	1
5	230	23.0	80	14	14	12	10	10	9	8	7	7	6

*These fuses are maximum for protection at wiring only and do not give motor overload protection.
**Wire sizes shown permit maximum voltage drop at 5%.
† Horsepower
†† American Wire Gauge

5.7.3 Metering

A water meter is a management tool that is desirable for more sophisticated systems. If the amount of water produced is known, excessive use can be identified. Excessive use often indicates leakages in the system or unauthorized use. In addition, water use trends can be identified and system design adjusted to meet these trends.

5.7.4 Accessibility of Equipment

The pump and motor must be easily accessible for repair, replacement, operation and preventive maintenance. The pump and motor should be accessible in all weather conditions.

5.7.5 Minimizing Contamination Potential

Water sources must be protected to prevent contamination by using well slabs set on mounds and well seals. Draining wastewater away from the well, extending the casing at least 15 cm above the well slab and using materials that are clean and meant to be used in water systems are other ways to prevent contamination. See Figure 5 - 15. Cement well slabs/pads size should be a minimum of 12 square feet (ft^2) as individual site conditions and space allows. Cement pads that are inadequately sized create muddy, slippery, and unsanitary conditions near the wellhead and should be avoided.

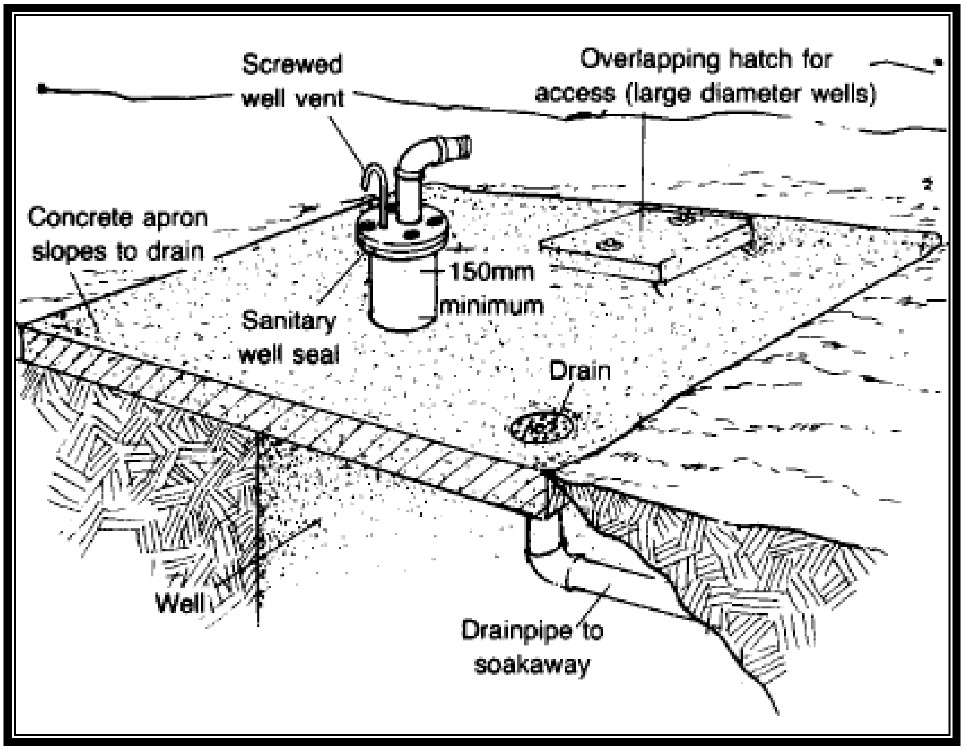


Figure 5 - 15 Minimizing Pollution Potential

5.7.6 Typical Pump Installation Drawings

A centrifugal pump is installed as shown in Figure 5 - 16. These pumps are relatively simple to install. Centrifugal pumps do not normally require hoists or A-frames.

Submersible pumps are typically installed as shown in Figure 5 - 17 and in Figure 5 - 18. Figure 5 - 19 shows pump and piping installation.

Line shaft turbines, also called deep well and vertical axis turbines, require a tripod, block and tackle, pipe holder and pipe clamps. Since the motor is not in water, it is unlikely that it will short out. Vertical alignment is much more critical with a line shaft turbine than with a submersible pump because of the shaft which connects the motor to the pump.

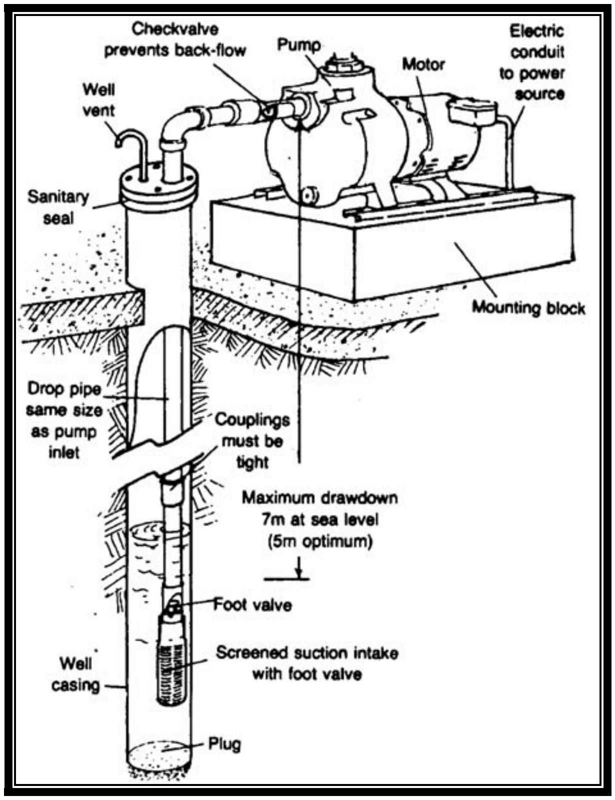


Figure 5 - 16 Typical Close-Coupled or Frame-Mounted Centrifugal Pump Installation

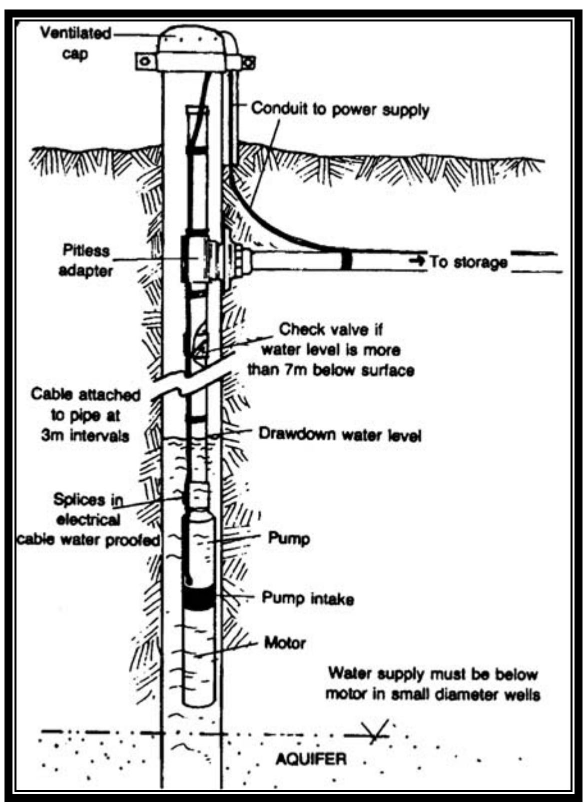


Figure 5 - 17 Installation of Submersible Pump with Underground Discharge

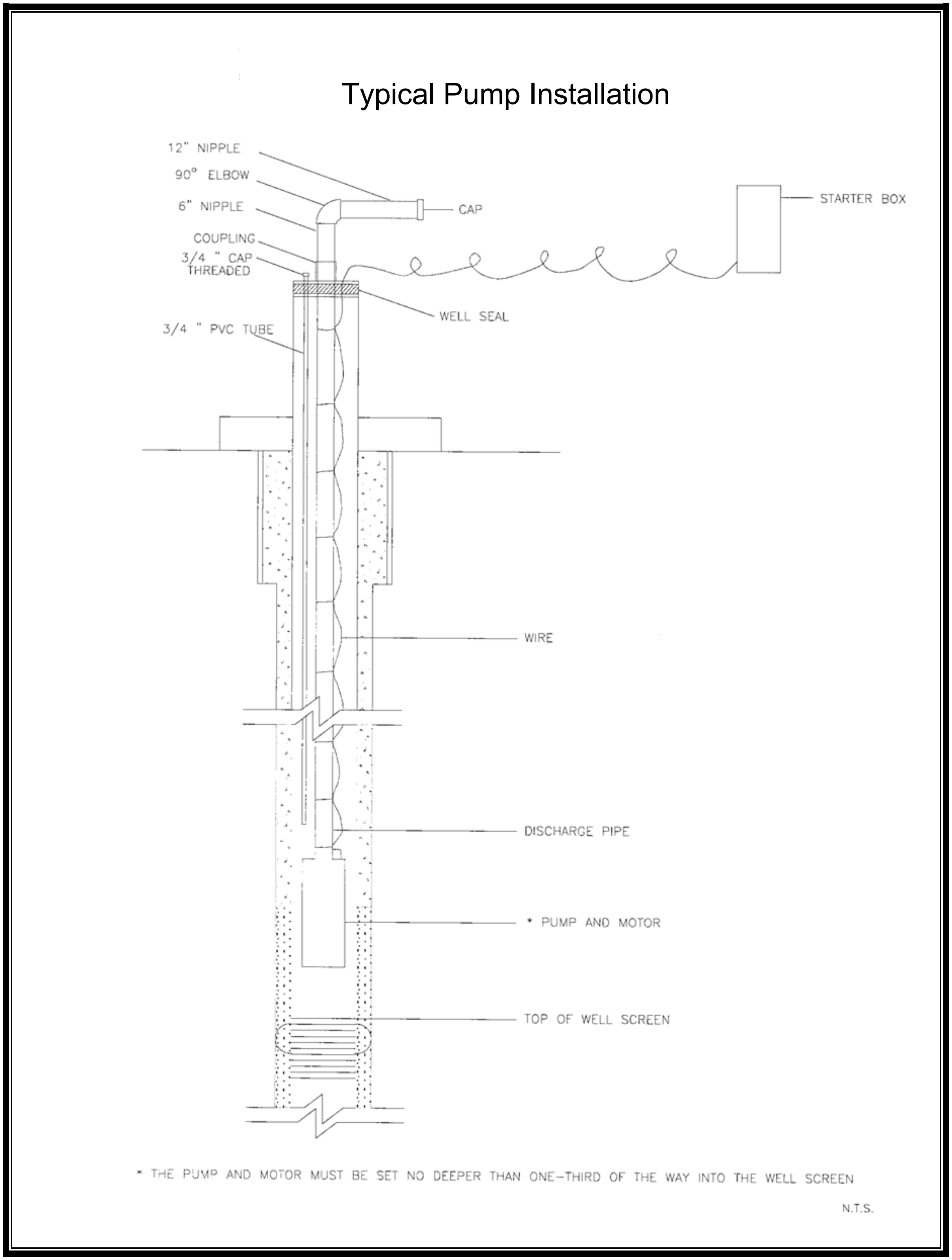


Figure 5 - 18 Installation of Submersible Pump with Above Ground Discharge

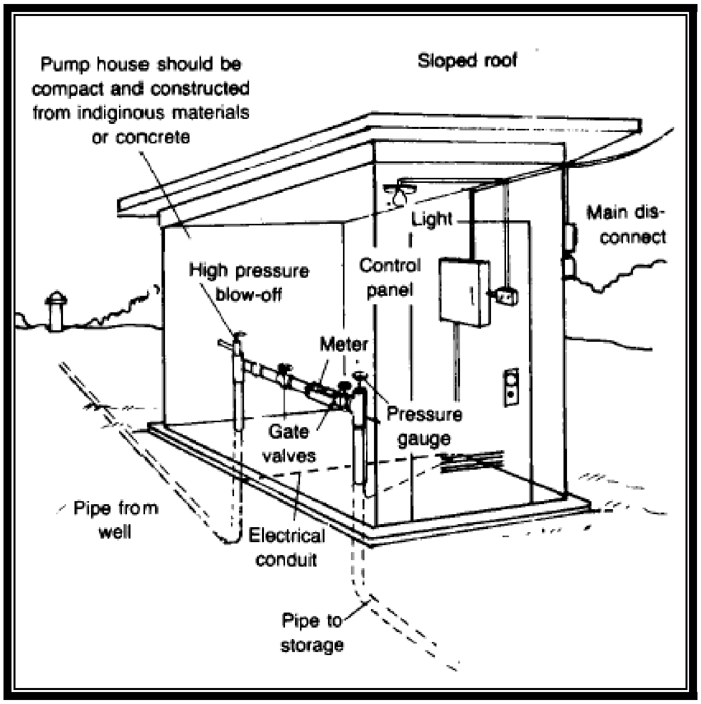


Figure 5 - 19 Pump House for Submerged Pump

Typical installations are shown in Figure 5 - 20. Figure 5 - 21 shows how line shaft vertical turbine units are installed or removed. Windmill installations are similar to vertical axis turbines. A typical installation is shown in Figure 5 - 22.

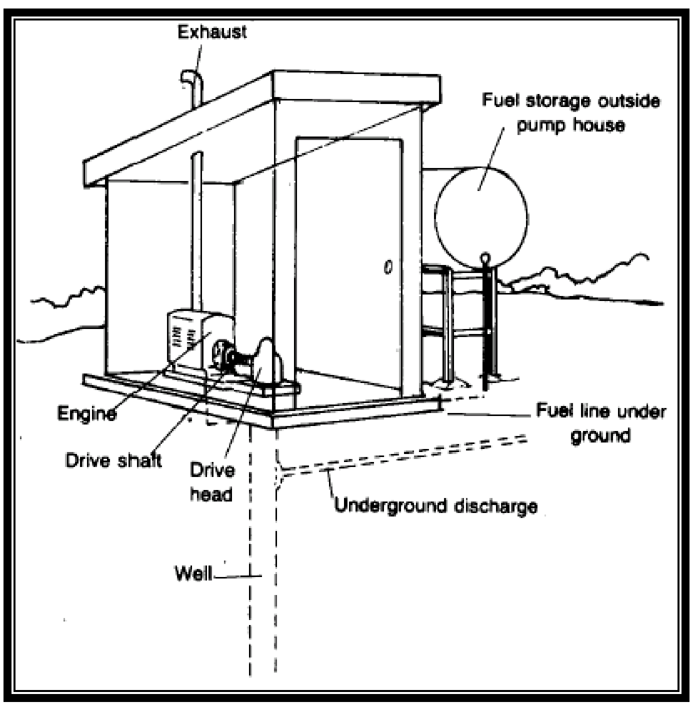
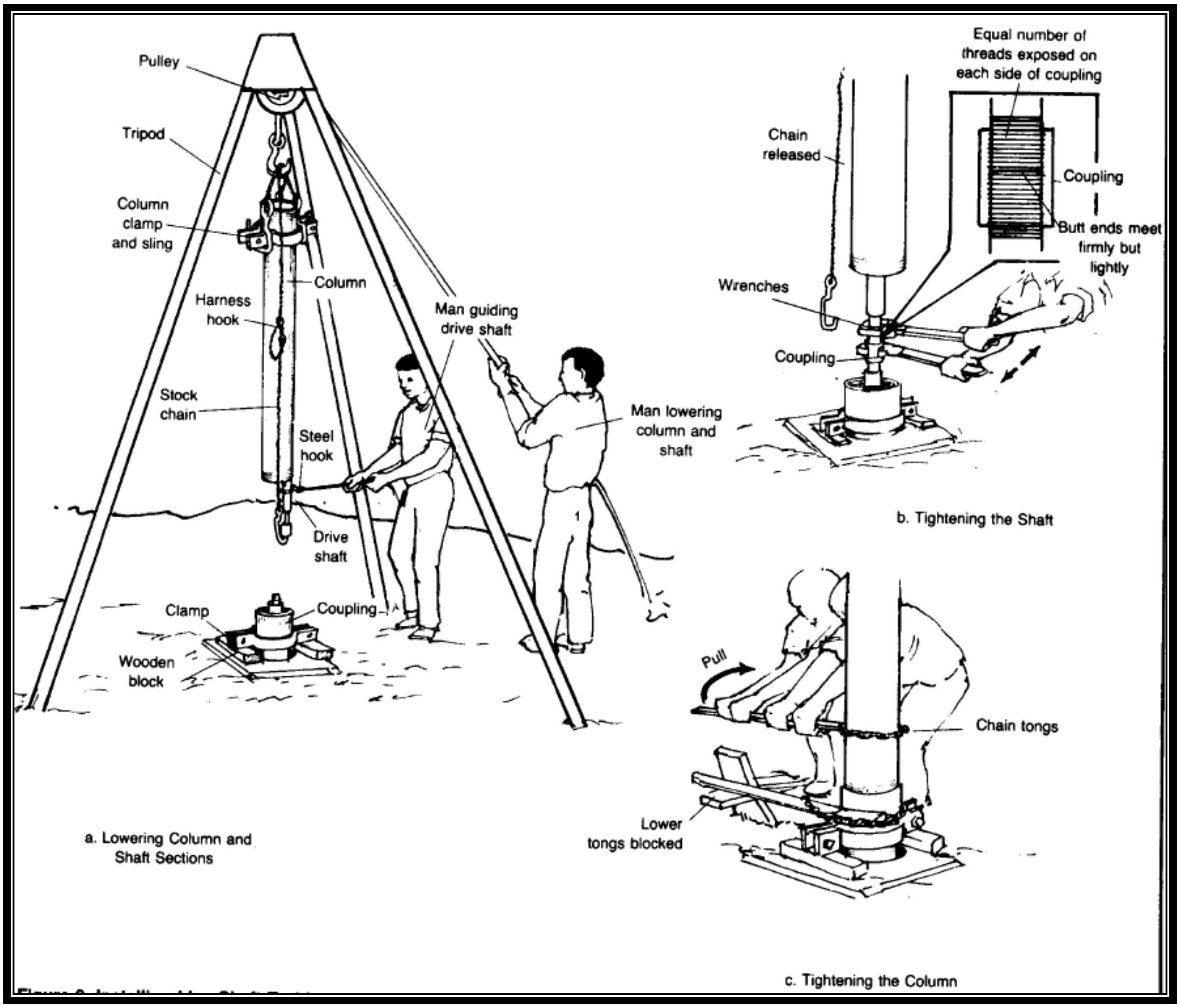


Figure 5 - 20 Pump House for Internal Combustion Engine and Line Shaft Vertical Turbine Pump



a. Lowering Column and Shaft Sections

b. Tightening the Shaft

c. Tightening the Column

Figure 5 - 21 Installing Line Shaft Vertical Turbine Pumps

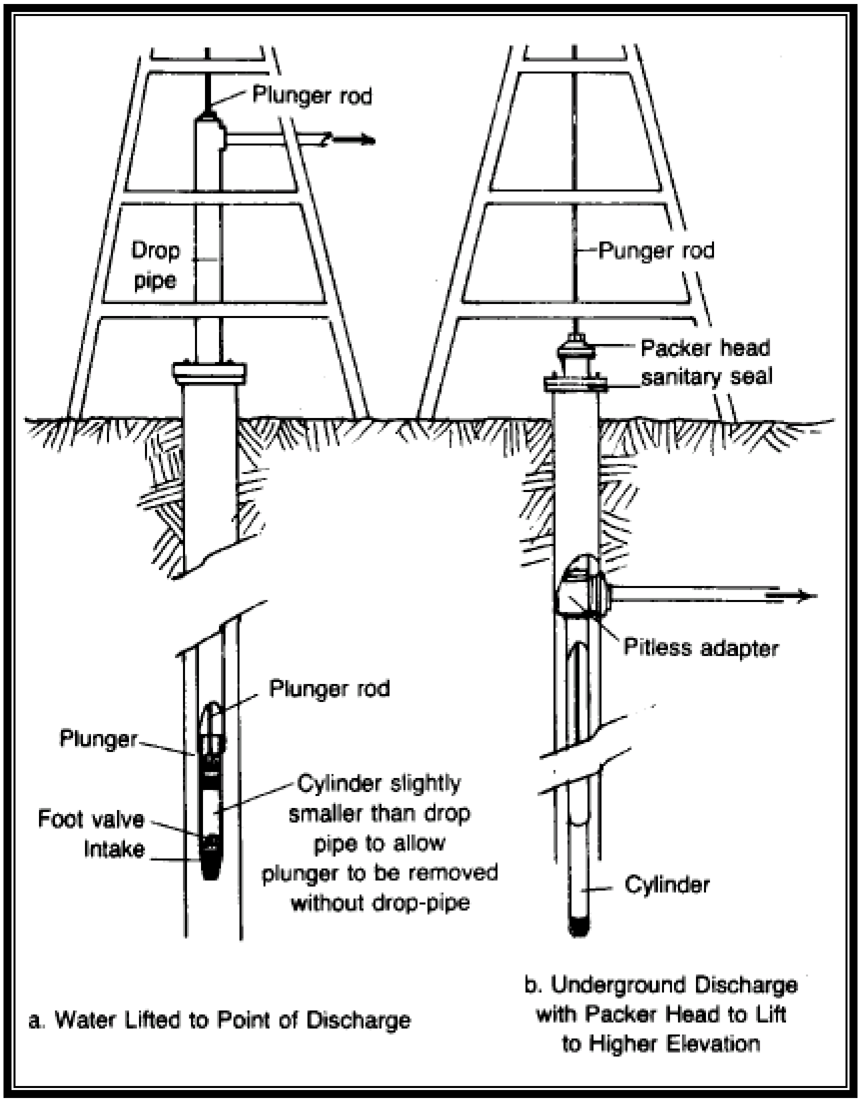


Figure 5 - 22 Typical Windmill Installations

5.8 Example Problem: Submersible Pump Sizing

A submersible pump is to be sized from the following information determined during the well drilling exercise:

- Safe well yield: 30 gpm (from pumping test),
- Pump Capacity: 30 gpm,
- Static Water Level: 64 ft,
- Drawdown at 30 gpm: 45 ft,
- Well Diameter: 6 inches, and
- Electrical: Single phase, 230 volt, 60 Hertz (Hz) power is available at the well.

See Figure 5 - 23 for graphical representation. A water storage tank will be installed on a hilltop at a distance of 1100 ft horizontally from the well. The top of the tank will be 98 ft higher in elevation than the well. The following subsections calculate proper pump pipe sizing.

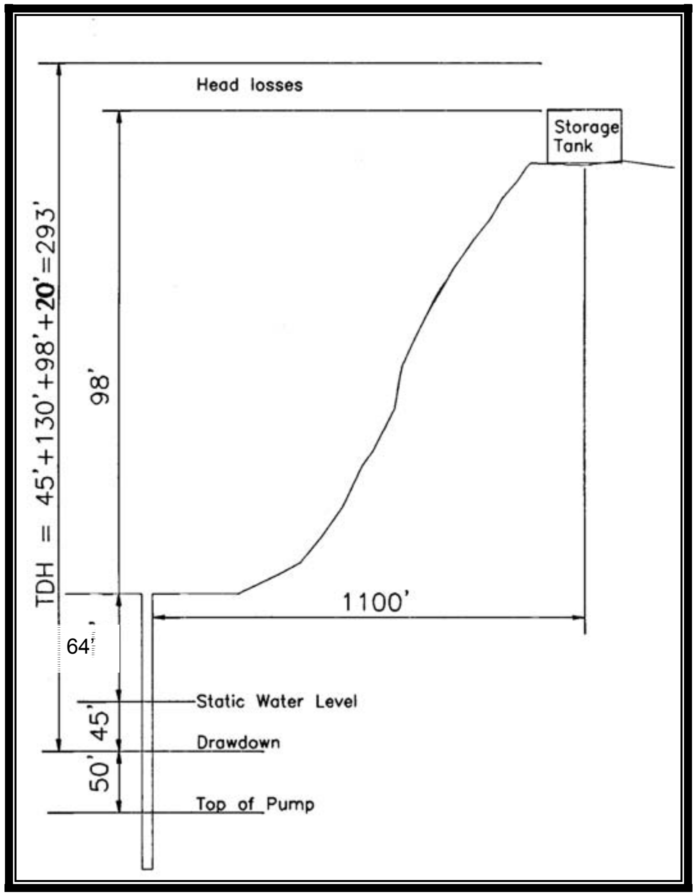


Figure 5 - 23 Example for Submersible Pump Sizing

5.8.1 Determine Piping Diameter

Piping will be sized for a velocity of 2.5 feet per second (fps) using the formula:

Diameter = $\sqrt{0.167Q} = \sqrt{0.167 \times 30}$.

Round down to the nearest pipe size and use 2-inch diameter piping. See Section 5.7 for details of calculation.

5.8.2 Calculate Friction (Head) Losses

Total pipe length from the pump to the storage tank =
1100 ft + 64 ft + 45 ft + 50 ft = 1259 ft = 12.59 (100 ft of pipe)

A value of 1.81 ft (per 100 ft of pipe) is found by using the Pipe Friction Loss Table in Appendix H, page H - 2, for 2-inch plastic pipe and 30 gpm. Minor losses through valves and fittings etc. will be neglected in this example.

The friction loss will be:
1.81 ft / (100 ft of pipe) x 12.59(100 ft of pipe) = 23 ft.

5.8.3 Calculate the Pump Total Dynamic Head

The TDH is the sum of the static lift, the drawdown and the friction losses:

Static Lift	= 98 ft + 64ft =	162 ft
Drawdown	=	45 ft
Friction Losses =		+23 ft
TDH	=	230 ft

5.8.4 Calculate Pump (Brake) Horsepower

$$\textbf{bhp} = \frac{\textbf{Q x TDH}}{\textbf{3960 x Efficiency}} = \frac{\textbf{30 gpm X 230 ft}}{\textbf{3960 x 0.60}} = \textbf{2.9 (use 3.0 HP)}$$

bhp = Brake horsepower
3960 = Constant for Calculating Horsepower
Efficiency = Efficiency of pump (if not stated, assume 60%)

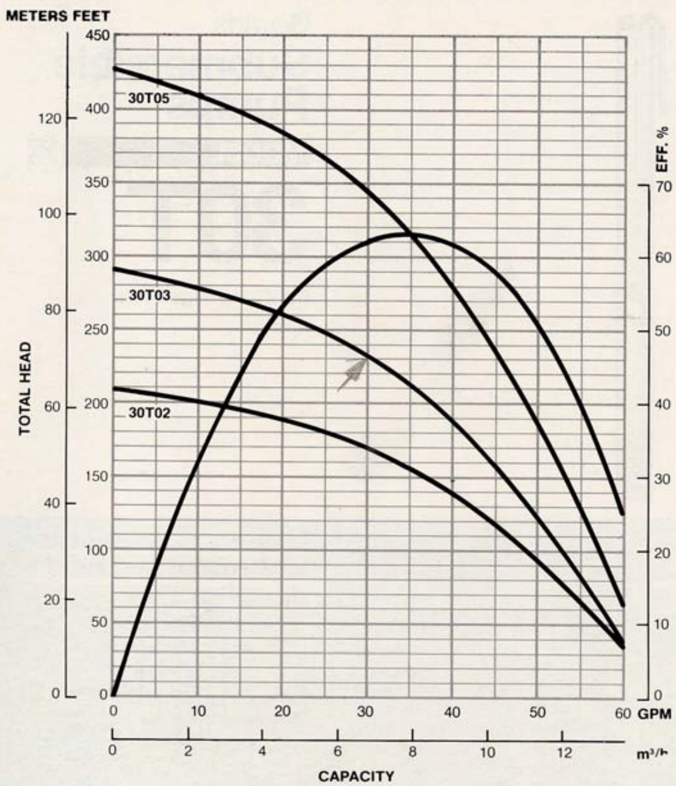
5.8.5 Selecting a Pump

A 4-inch diameter pump will be selected for the 6-inch well for reasons mentioned in the Introduction of this section. Regardless of manufacturer recommendations, submersible pumps greater than 4 inches in diameter shall not be used in 6-inch wells. A pumping test is essential to proper pump size. See the HCA Well Drilling Manual, Chapter 5, for an example pumping test form. A pump performance curve, taken from a pump manufacturer's literature, is shown in Figure 5 - 24. The characteristic curve for the pump is found by intersecting lines for 30-gpm flow on the horizontal axis and 230 ft TDH on the vertical axis. An arrow marks the location of this intersection point.

The pump model number, 30T03 is found by following the characteristic curve up and to the left. The actual pump efficiency is found by extending a line from the 30 gpm mark on the horizontal axis upward to the efficiency curve (parabolic shaped curve) and then reading the value on the axis on the right side. In this case the efficiency is 62%.

The complete model number for the pump, 30T03412, is found in the Dimensions and Weights Table located in Figure 5 - 24 below the performance curves. This model number indicates a 30 gpm, 3 HP, 4-inch diameter, single phase, 230-volt pump and motor. This pump will have 11 stages or impellers. However, the pump manufacturer should be contacted prior to ordering the pump to assure proper selection. Other features about the pump are shown in Figure 5 - 25.

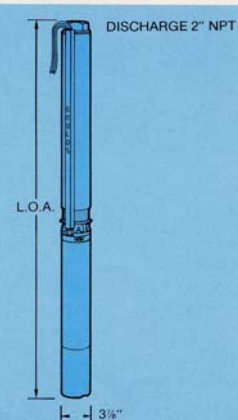
Goulds
Submersible Pumps
MODEL
30T



DIMENSIONS AND WEIGHTS

(All dimensions in inches and weights in lbs.)
(Do not use for construction purposes.)

HP	Stages	Model No.	Length	Weight
2	8	30T02412	42 5/8	75
		30T02432,34	41 1/8	70
3	11	30T03412	51 5/8	96
		30T03432,34	48 5/8	83
5	16	30T05412	67 5/8	127
		30T05432,34	61 5/8	111



GOULDS PUMPS, INC.
SENECA FALLS NEW YORK 13148

SPECIFICATIONS ARE SUBJECT TO CHANGE WITHOUT NOTICE.

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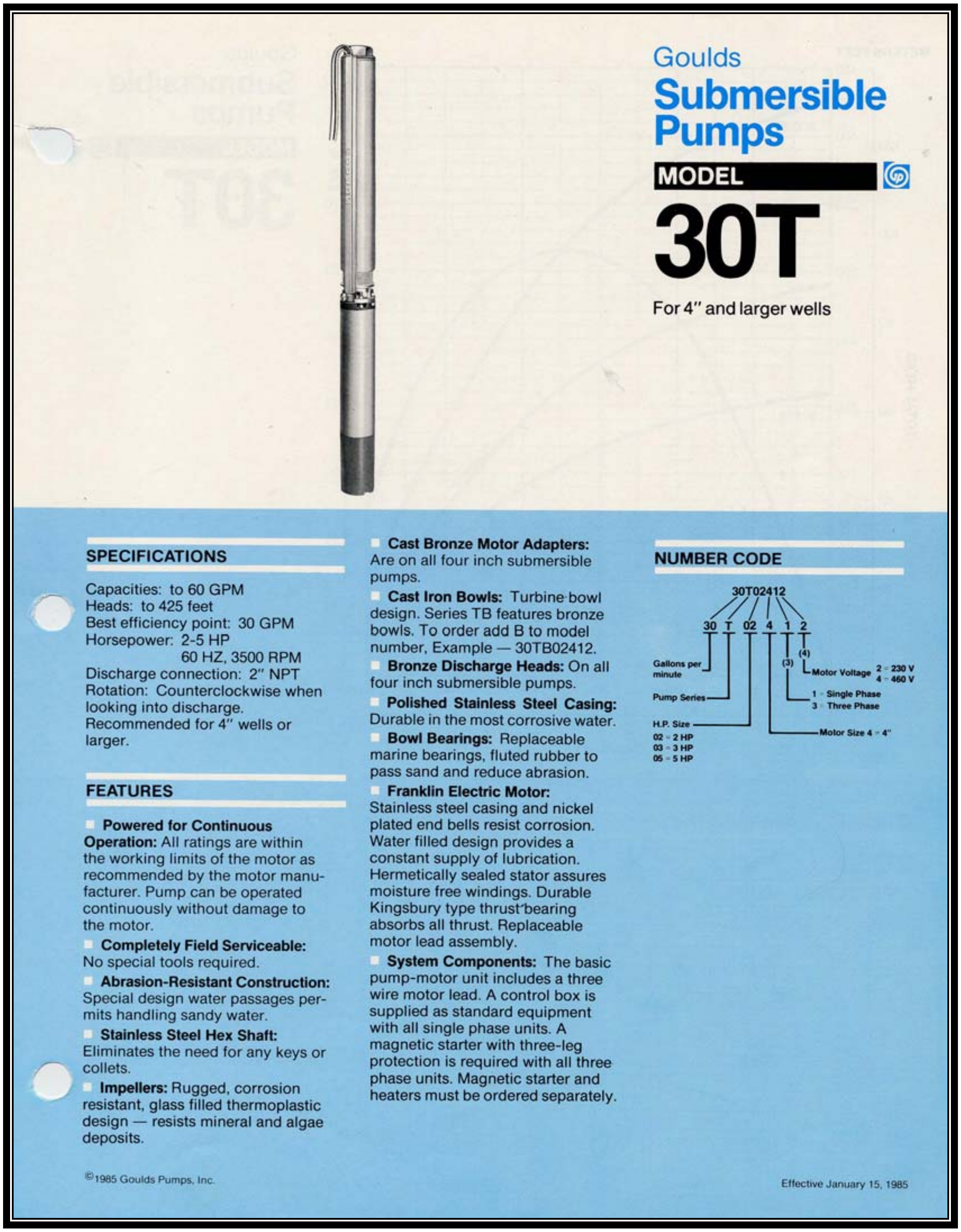
Figure 5 - 24 Submersible Pump Performance Curve



Goulds

Submersible Pumps

MODEL

30T

For 4" and larger wells

SPECIFICATIONS

Capacities: to 60 GPM
Heads: to 425 feet
Best efficiency point: 30 GPM
Horsepower: 2-5 HP
60 HZ, 3500 RPM
Discharge connection: 2" NPT
Rotation: Counterclockwise when looking into discharge.
Recommended for 4" wells or larger.

FEATURES

- **Powered for Continuous Operation:** All ratings are within the working limits of the motor as recommended by the motor manufacturer. Pump can be operated continuously without damage to the motor.
- **Completely Field Serviceable:** No special tools required.
- **Abrasion-Resistant Construction:** Special design water passages permits handling sandy water.
- **Stainless Steel Hex Shaft:** Eliminates the need for any keys or collets.
- **Impellers:** Rugged, corrosion resistant, glass filled thermoplastic design — resists mineral and algae deposits.
- **Cast Bronze Motor Adapters:** Are on all four inch submersible pumps.
- **Cast Iron Bowls:** Turbine bowl design. Series TB features bronze bowls. To order add B to model number, Example — 30TB02412.
- **Bronze Discharge Heads:** On all four inch submersible pumps.
- **Polished Stainless Steel Casing:** Durable in the most corrosive water.
- **Bowl Bearings:** Replaceable marine bearings, fluted rubber to pass sand and reduce abrasion.
- **Franklin Electric Motor:** Stainless steel casing and nickel plated end bells resist corrosion. Water filled design provides a constant supply of lubrication. Hermetically sealed stator assures moisture free windings. Durable Kingsbury type thrust bearing absorbs all thrust. Replaceable motor lead assembly.
- **System Components:** The basic pump-motor unit includes a three wire motor lead. A control box is supplied as standard equipment with all single phase units. A magnetic starter with three-leg protection is required with all three phase units. Magnetic starter and heaters must be ordered separately.

NUMBER CODE

30T02412

30 T 02 4 1 2

Gallons per minute
Pump Series
H.P. Size
02 - 2 HP
03 - 3 HP
05 - 5 HP
Motor Size 4 - 4"
(3)
1 - Single Phase
3 - Three Phase
(4)
Motor Voltage 2 - 230 V
4 - 460 V

Effective January 15, 1985

Figure 5 - 25 Submersible Pump Technical Data

SECTION 6

WATER STORAGE TANKS

EXECUTIVE SUMMARY

Water storage tanks are a necessary component of water systems. Their purpose is to store water for peak usage and for a possible temporary interruption of water supply. The types of tanks presented in this section are ground storage tanks and elevated storage tanks and represent, as the name implies, tanks that are built at ground level and tanks that are elevated above ground level. Both gravity systems (systems depending on vertical distance) and pneumatic (pressurized) systems will be described. The various available construction materials are also discussed. The alternative selected (type of tank and construction materials) will be based on the local topography, real estate requirements, local availability of construction materials/skills, local preferences, and costs.

General Requirements:

1. All water tanks should be covered and ventilated to prevent contamination and growth of algae.

2. A manway above the high water line is required on each tank to allow access for cleaning and maintenance.

3. Drainpipes with a suitable shut-off valve should be installed for all tanks.

4. For all prefabricated tanks and support structure, the manufacturers plans, specifications, and recommendations shall be followed. This shall include the foundations, tank assembly, and coatings, if required.

5. For gravity systems, it is recommended that the distribution system provided should have a minimum height of 33 feet from the low water elevation in the storage tank and the outlet valves (yard hydrant). This height will provide a minimum static pressure of 14.3 psi at the hydrant. For pneumatic systems, an operating range of 20-40 psi is recommended.

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For all prefabricated tanks and support structure, the manufacturers plans, specifications, and recommendations shall be followed. This shall include the foundations, support structures, tank assembly, and coatings, if required.

6.2 Storage Tank Capacity

Ground storage and elevated storage tanks are normally sized to contain the daily volume based on the number of users (capita) multiplied by the average water consumption per capita. The number of users should be based on the current population multiplied by a growth factor based on the yearly growth rate for a design period of 20 years. If no data is available to estimate the existing growth rate, a yearly growth rate of 4% is recommended. The growth factor for a yearly growth rate of 20 years is 1.80. See Table 2 – 2 for the population growth factors used to estimate the future population of a community. The estimated water consumption from a yard hydrant is 10 gpcd. So, the required storage capacity is the projected population in 20 years times 10 gpcd.

Pneumatic tanks are sized to provide adequate chlorine detention time or pump run time. See paragraph 6.4 for discussion of pneumatic tank sizing.

6.3 Ground Level Storage Tanks

For the community hydrant type water distribution systems, the recommended minimum bottom elevation of the storage tank is 33 ft above the ground location of the highest hydrant in the system. The difference in elevation is necessary to provide enough pressure for the water system to be usable; approximately 14.3 psi. If there is high ground available that meets the required minimum difference in elevation, a ground storage tank can provide the water demand at an adequate pressure.

Figure 6 - 1 and Figure 6 - 2 show alternate piping schemes to pump water to a ground storage tank and gravity feed the distribution system. Figure 6 - 3 illustrates how to connect supply and distribution lines to the ground storage tank.

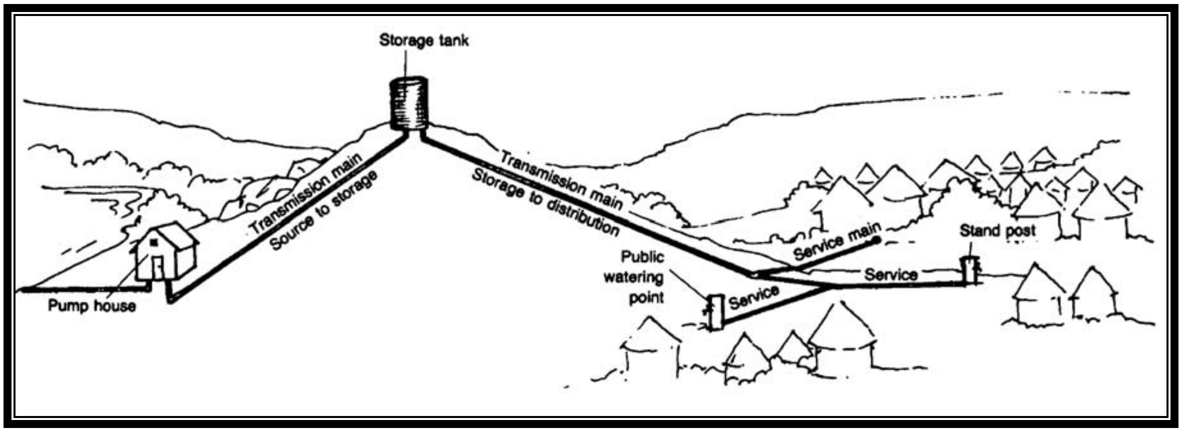

Figure 6 - 1 Location of Ground Storage Tank

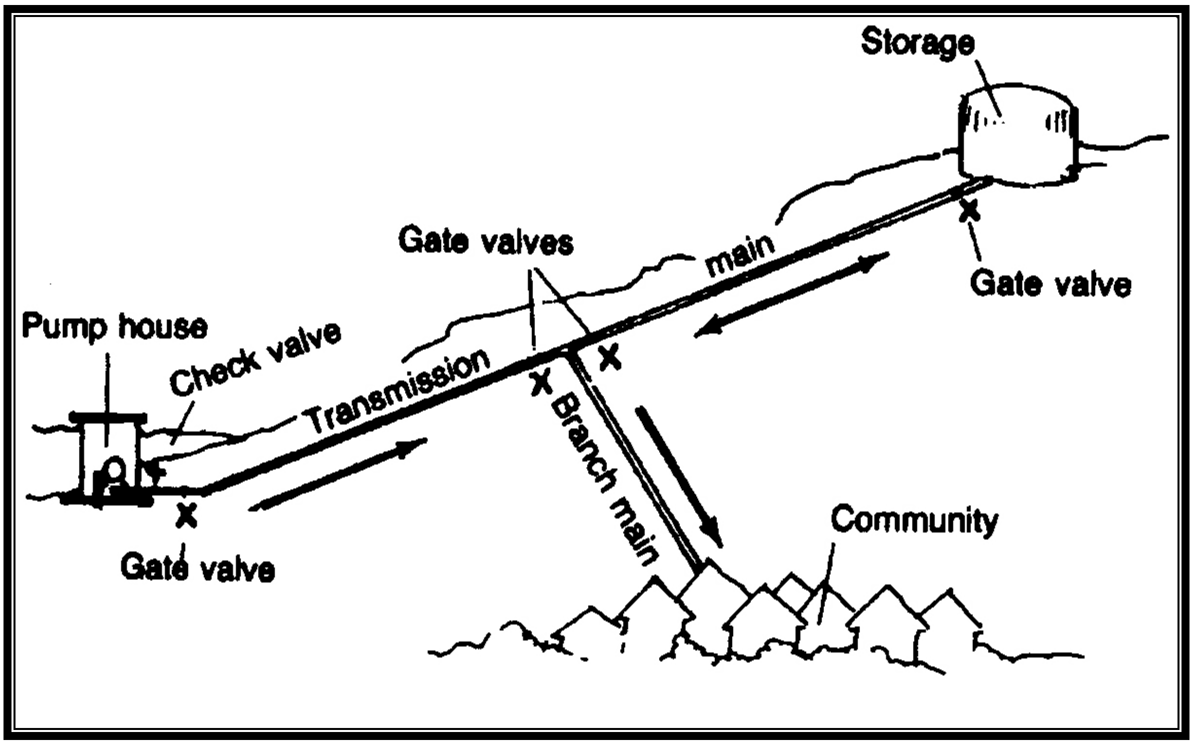

Figure 6 - 2 Alternate Location of Ground Storage Tank

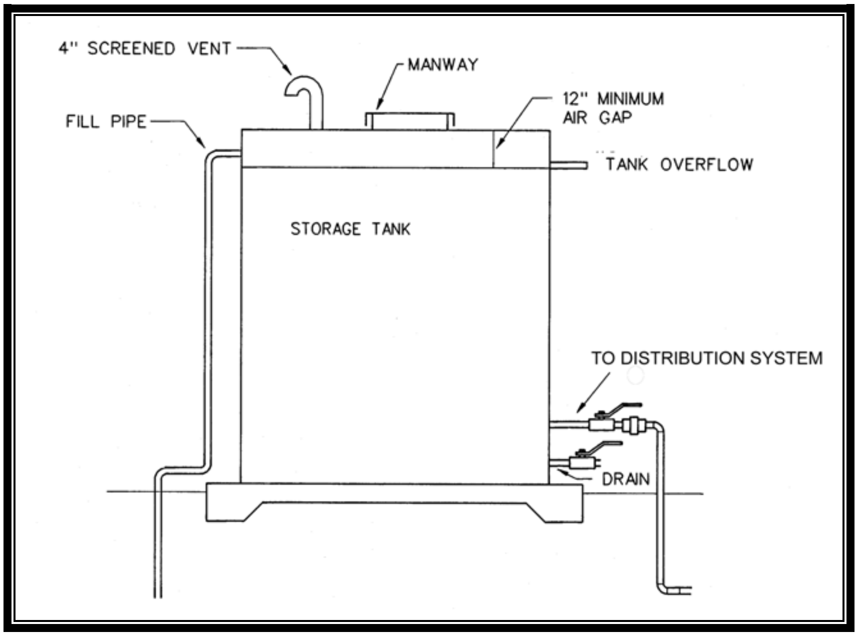

Figure 6 - 3 Typical Ground Storage Tank Piping Detail

6.4 Elevated Storage Tanks

Where there is insufficient difference in ground elevation, a platform or structure of adequate height must be provided for the storage tank. Tanks may be constructed of reinforced concrete, steel, or plastic. The support structures must be constructed of steel or reinforced concrete. Elevated steel water towers are costly even for the small volumes and relatively low heights required. Pre-engineered steel tanks and support structures are available from suppliers and may be purchased and assembled at the project site. Tanks and supports may be welded or bolted as appropriate for the local conditions. The use of galvanized steel support members and tanks or tank parts should be considered. Elevated reinforced concrete water towers are less costly to construct but require more design and construction time. Concrete tanks require less long term maintenance than steel tanks. A structural engineer should design the concrete storage tank and supervise the construction. As an alternative to elevated steel or concrete water tanks, a steel platform for a polyethylene (PE) water tank could be designed.

6.5 Pneumatic Storage Tanks

Pneumatic storage tanks should also be considered in cases where the well pumping tests indicate that the well is capable of yielding more than the highest water demand for the planned distribution system. Pneumatic tanks use compressed air in the tank to provide adequate pressure for the distribution system. Larger pneumatic tank systems usually are designed with an air charging system (air compressor) to maintain the proper air/water ratio in the tank. For simplicity of design and operation and maintenance, the use of air charging systems is not recommended for these projects.

Smaller (up to approximately 160 gallons) pneumatic tanks are available that use a rubber bladder or diaphragm to separate the water and the air. This results in a greater usable capacity and no need for an air charging system. The use of these type pneumatic tanks should also be considered where appropriate.

6.5.1 Pneumatic Tank Advantages

Pneumatic tanks should be the least costly system for locations where there is insufficient ground level above the community hydrant locations. Pneumatic tanks can be installed at ground level. Chlorine metering pumps can be installed that will operate concurrently with the submersible well pump to inject a chlorine solution into the well water. Refer to Section 5 and Appendix F for further details. An additional advantage is that the pump controls could be set to automatically start when the pressure in the system drops to 20 psi and stop when the system pressure reaches 40 psi (or other pressures as appropriate for the local conditions).

6.5.2 Sizing a Pneumatic Tank

Unlike ground storage tanks or elevated tanks that are sized for a daily requirement, pneumatic tanks are sized based on pump capacity and a chlorine contact time of 15 minutes. The useful volume of a pneumatic tank is only about 25% of the total tank volume. The useful volume is the volume of water in the tank between the high and low-pressure settings. For a 15-gpm-pump rate, the total tank volume is equal to:

$$\text{Volume} = \frac{15 \text{ gpm} \times 15 \text{ min}}{0.25} = 900 \text{ gallons}$$

For all practical situations, this calculated volume meets or exceeds the minimum pump cycle time requirements.

The sizing of bladder or diaphragm pneumatic tanks should follow the manufacturer's recommendations. Care should be given to assure that the 15-minute chlorine contact time is provided in the tank.

6.5.3 Well House/Secure Area

The water storage system and controls should be protected from the weather and mischief. The pneumatic tank and controls should be installed in a secure area or well house. It is not necessary to house the entire tank inside of a building. As a minimum, the secure area should have a roof over the mechanical and electrical components and fence with a lockable gate. The tank should be located in a convenient and accessible location near the well and the community hydrants. Provide convenience electrical outlets and lighting for the area.

6.6 Construction of Ground Storage Tanks

Construction of steel water tanks including foundations should be in accordance with manufacturer's plans and specifications and construction recommendations. The steel tank fabricators may be contracted to furnish skilled laborers to assemble the tanks on site. Construction of reinforced concrete storage tanks should be in accordance with the engineer's plans and specifications.

Construction of storage tanks on site using bricks and mortar or stones and mortar on site is not recommended.

6.6.1 Prefabricated Storage Tanks

Prefabricated storage tanks are available in many different sizes and shapes in various materials of construction. Cylindrical polyethylene tanks are available in Latin America and are commonly used. This alternative may be the most cost effective. Prefabricated water tanks are provided with vents, connections for valves and fittings for the supply from the well or water treatment system, the connection to the distribution system water, a manway, a cover, and drain.

6.6.2 Foundation for Ground Storage Tanks

Construction of a foundation for ground storage tanks will be necessary. For water tanks less than 5000 gallons, a concrete slab 6 inches in depth with a continuous footing as detailed in Figure 6 - 4 is recommended. A square or rectangular slab is recommended for all tanks including those with round bottoms. The length and width of the slab should allow a minimum clearance of two feet on all sides of the tank.

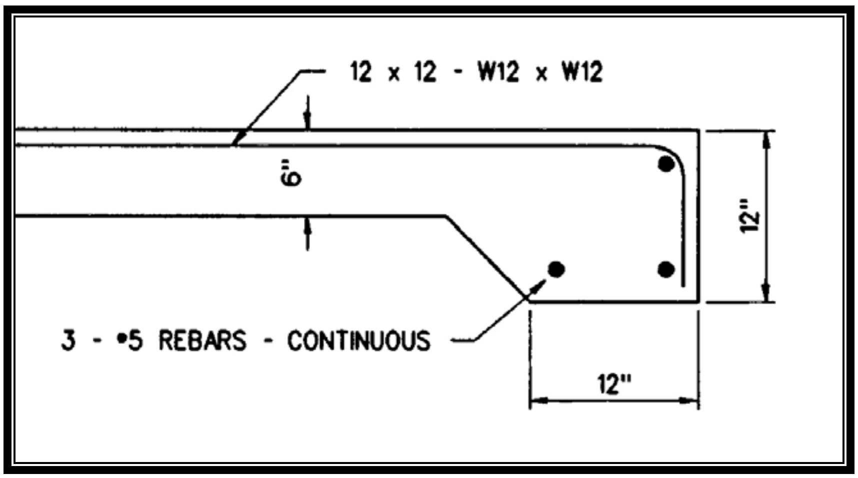

Figure 6 - 4 Ground Storage Tank Foundation Detail

6.7 Construction of Elevated Storage Tanks

6.7.1 Elevated Steel Storage Tanks

Construction and finishing of prefabricated elevated steel storage tanks including foundations and surface coatings should follow the manufacturer’s recommendations. The assembly or erection of steel tanks requires craftsmen skilled in the construction of these structures.

Small prefabricated support structures and tanks may be locally available and should be considered. These structures will save design and construction time. They require placement of the structure on a suitable foundation. The foundation should be designed and constructed in accordance with the manufacturer’s recommendations.

Ungalvanized steel tanks require painting on both inside and outside surfaces to prevent rusting. The interior coatings shall be approved for potable water applications. For an example of an elevated steel storage tank see Figure 6 - 5.

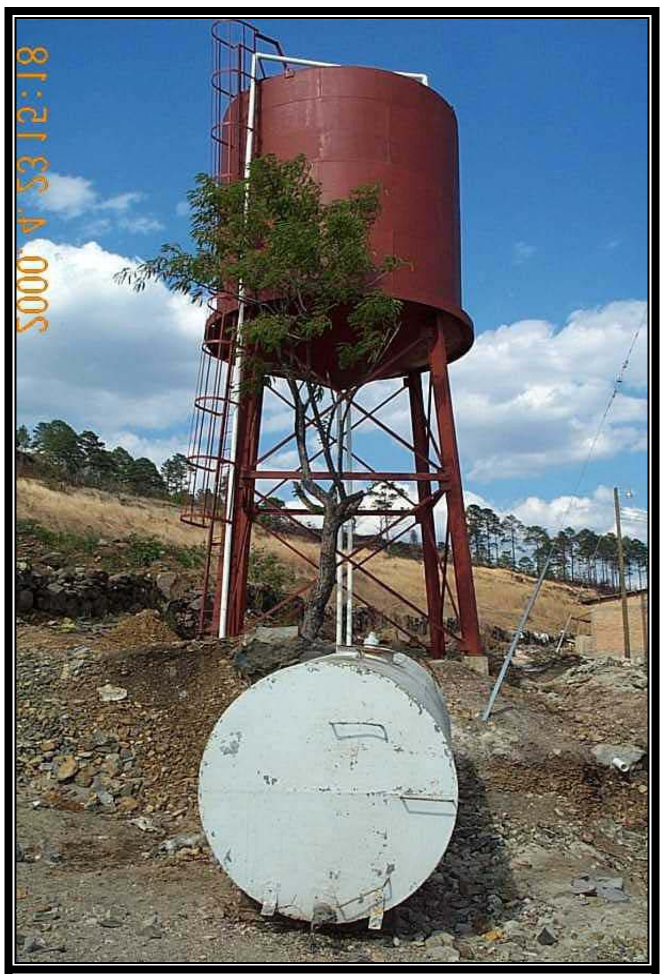

Figure 6 - 5 Elevated Steel Storage Tank

6.7.2 Elevated Concrete Storage Tanks

An example of a built-in-place reinforced concrete elevated storage tank is shown in Figure 6 - 6. Generally, this type of structure will require time and resources outside that available for the exercise. However, this type of structure may be needed for the larger storage requirements. A structural engineer should design the elevated concrete storage tanks and supervise the construction.

Figure 6 - 6 Elevated Concrete Storage Tank

6.7.3 Elevated Platform with Polyethylene Tank

As a less costly alternative to elevated steel or concrete water tanks, a steel support structure and a pre-fabricated polyethylene water tank could be specified. For smaller applications, the support structures may also be prefabricated and transported to the site. See Figure 6 - 7 for an example of a small polyethylene tank with prefabricated support structure.

Figure 6 - 7 Elevated Polyethylene Storage Tank

SECTION 7

WATER DISTRIBUTION SYSTEMS

EXECUTIVE SUMMARY

The typical small water distribution system that US Southern Command will install consists of piping from the well site to the storage tank and from the storage tank to yard hydrants for the public to fill their own water containers. If the local water authority requests that the water supply from the new well be connected to an existing water distribution system, coordination should be made with the USACE, Mobile District. Design of this type distribution system is beyond the intent of this manual. American Water Works Association (AWWA) and American Society of Testing and Materials (ASTM) references are included in this section to use in ordering pipe materials. These references specify raw materials and the dimensional requirements used in the manufacture of pipe and fittings. This information will be beneficial for procurement of the piping system.

7.1 Introduction

The typical small water distribution system that US Southern Command will install consists of piping from the well site to the storage tank and from the storage tank to yard hydrants for the public to fill their own water containers. If the local water authority requests that the water supply from the new well be connected to an existing water distribution system, coordination should be made with the USACE, Mobile District. Design of this type distribution system is beyond the intent of this manual. AWWA and ASTM references are included in this section to use in ordering pipe materials that meet minimum standards. Piping manufactured in the United States will use these references as standard practice. Many manufacturers in Latin America also use these standards for the manufacture of their products. This will be beneficial in procurement of pipes and fittings. Selection of materials is based on availability, price, construction methods, and durability. The operators' preferences should also be considered.

7.2 Pipe Sizing

Selection of water line size should be made on the basis of flow velocities at the design flow capacity. For USSOUTHCOM designs, the velocities of flow should be kept in the range of 2 to 3 fps. Use Table 7 - 1 for selecting water lines.

Table 7 - 1 Water Line Pipe Size

Flow Range (gpm)	Recommended Pipe Size (inches)
5 to 10	1
10 to 20	1-1/2
20 to 32	2
32 to 45	2-1/2
45 to 75	3
75 to 120	4
120 to 190	5
190 to 270	6

Note: If the difference in elevation from the pump to the storage tank or from the storage tank to the lowest point in the distribution system exceeds 200 ft, there may be problems with excessive pressure and possible water hammer. An engineer experienced in designing water distribution systems should perform a hydraulic analysis, including water hammer transient pressure (surge) analysis. Contact the Mobile District early in the planning phase, if such situations exist.

7.2.1 Materials for Water Lines

Selection of materials is based on availability, price, construction methods, and durability. The operators' preferences should also be considered. Any of the materials discussed below will provide satisfactory service for the anticipated projects.

Piping for water lines less than 3 inches in diameter shall be galvanized steel, or PVC pipe. Piping for water lines 3 inches and larger shall be either PVC or ductile iron. PVC pipe should not be installed in any location where it will be exposed to direct sunlight.

7.2.2 Excavation, Trenching and Backfilling

Trenches should be excavated so that the minimum depth from the surface to the top of the pipe is approximately 24 inches. The trench width below the top of the pipe shall depend on the type of pipe used and the soil conditions. The pipe manufacturer's installation manual should provide this information. In general for USSOUTHCOM installations, the trench widths will be 12 to 24 inches plus the outside diameter of the pipe to be installed. A bedding material free of rocks or other objects 3 inches in diameter or larger shall be placed in the trench bottom to a depth of 6 inches prior to installing the water line. After the water line is installed, the initial backfill shall be placed in 6-inch lifts over the water line and each lift hand tamped to a depth of 12 inches above the top of the pipe. The final backfill shall be placed in 12-inch lifts and tamped to the ground surface. See Figure 7 - 1.

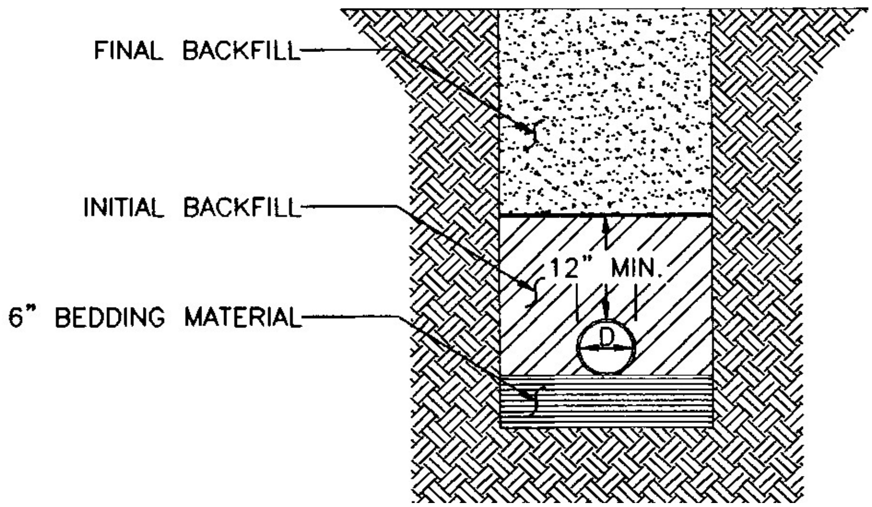

Figure 7 - 1 Pipe Trench Bedding Detail

7.3 Handling During Construction

Pipe and accessories shall be handled to ensure delivery to the trench in sound, undamaged condition, including no injury to the pipe coating or lining. If the coating or lining of any pipe or fitting is damaged, a repair shall be made. No other pipe or material shall be placed inside a pipe or fitting after the coating has been applied. Pipe shall be carried into position and not dragged. Use of pinch bars and tongs for aligning or turning pipe will be permitted only on the bare ends of the pipe. The interior of pipe and accessories shall be thoroughly cleaned of foreign matter before being lowered into the trench and shall be kept clean during laying operations by plugging or other approved method. Before installation, the pipe shall be inspected for defects. Material found to be defective before or after lying should be replaced with sound material. Rubber gaskets that are not to be installed immediately shall be stored in a cool and dark place.

7.4 Pipe Materials and Specifications

Pipe shall conform to the respective specifications and other requirements listed below. These specifications reference piping designed for 150 psi working pressure, which may be considerable more pressure than actually required for the project. Since piping designed for 150 psi working pressure is the standard, it is recommended that it be used. When ordering pipe valves or fitting in the U.S., furnish the specifications to the suppliers to assure procurement of the correct materials. See Appendix I for references to applicable AWWA and ASTM standards. Pipe meeting the standards below are readily available in the U.S. and may be available in other western hemisphere locations. Foreign manufacturers may reference U.S. standards in the absence of host country standards. In general, the ASTM 1785, schedule 40 and the ASTM 2241, SDR 17 pipe will be the least expensive to purchase and install for the typical USSOUTHCOM project.

7.4.1 PVC Plastic Pipe

Pipe, couplings and fittings for pipe shall be manufactured of material conforming to ASTM D 1784, Class 12454B.

1. PVC Pipe less than 4-inch diameter:

- **Screw-Joint:** Pipe shall conform to dimensional requirements of ASTM D 1785 Schedule 80, with joints meeting requirements of 150 psi working pressure and 200 psi hydrostatic test pressure, unless otherwise shown or specified. Pipe couplings, when used, shall be tested as required by ASTM D 2464.

- **Elastomeric-Gasket Joint:** Pipe shall conform to dimensional requirements of ASTM D 1785 Schedule 40, with joints meeting the requirements of 150 psi working pressure, 200 psi hydrostatic test pressure, unless otherwise shown or specified, or it may be pipe conforming to requirements of ASTM D 2241, elastomeric joint, with the following applications in Table 7 - 2 Pressure Chart.

Table 7 - 2 Pressure Chart

SDR	Maximum Working Pressure (psi)	Minimum Hydrostatic Pressure (psi)
17	150	200

NOTE: The SDR 17 pipe is rated for 150 psi working pressure. For very low-pressure applications, SDR 21 or SDR 26 is available at lower cost and may be suitable for the application.

- **Solvent Cement Joint:** Pipe shall conform to dimensional requirements of ASTM D 1785 or ASTM D 2241 with joints meeting the requirements of 150 psi working pressure and 200 psi hydrostatic test pressure.

2. PVC Pipe, 4 to 12-inch diameter: Pipe, couplings and fittings shall conform to AWWA C900, Class 150, CIOD pipe dimensions, elastomeric-gasket joint, unless otherwise shown or specified.

7.4.2 Ductile Iron Pipe

Ductile iron pipe shall conform to AWWA C151, with working pressure not less than 150 psi. Pipe shall be cement-mortar lined in accordance with AWWA C104. Linings shall be standard. Flanged ductile iron pipe with threaded flanges shall be in accordance with AWWA C115. Flanged pipe connections cannot be buried.

7.4.3 Galvanized Steel Pipe

Galvanized steel pipe shall conform to ASTM A 53, standard weight. Typically schedule 40 can be used for all projects.

7.5 Fittings and Specials

Typical fittings and specials are shown in Figure 7 - 2.

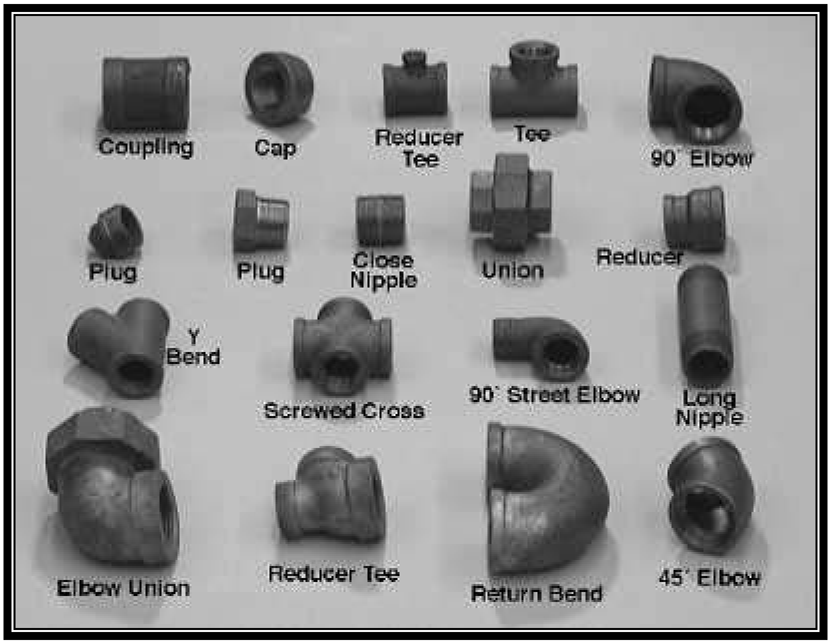

Figure 7 - 2 Typical Fittings

7.5.1 PVC Pipe System

1) **Pipe less than 4-inch diameter**: Fittings for threaded pipe with less than 4-inch diameters shall conform to requirements of ASTM D 2464, threaded to conform to the requirements of ASME B1.20.1 for use with Schedule 80 pipe and fittings; fittings for solvent cement jointing shall conform to ASTM D 2466 or ASTM D 2467; and fittings for elastomeric-gasket joint pipe shall be iron conforming to AWWA C110 or AWWA C111. Iron fittings and specials shall be cement-mortar lined (standard thickness) in accordance with AWWA C104.

2) **Pipe 4-inch diameter and larger**: Fittings and specials for pipes with diameters 4 inches and larger shall be iron, bell end in accordance with AWWA C110, 150 psi pressure rating except that profile of bell may have special dimensions as required by the pipe manufacturer; or fittings and specials may be of the same material as the pipe with elastomeric gaskets, all in conformance with AWWA C900. Iron fittings and specials shall be cement-mortar lined (standard thickness) in accordance with AWWA C104. Fittings shall be bell and spigot or plain end pipe, or as applicable. Ductile iron compact fittings shall be in accordance with AWWA C153.

7.5.2 Ductile Iron Pipe Systems

Fittings and specials shall be suitable for 150 psi pressure rating, unless otherwise specified. Fittings and specials for mechanical joint pipe shall conform to AWWA C110. Fittings and specials for use with push-on joint pipe shall conform to AWWA C110 and AWWA C111. Fittings and specials for grooved and shouldered end pipe shall conform to AWWA C606.

Fittings and specials shall be cement-mortar lined (standard thickness) in accordance with AWWA C104. Ductile iron compact fittings shall conform to AWWA C153.

7.5.3 Galvanized Steel Pipe

Steel fittings shall be galvanized. Screwed fittings shall conform to ASME B16.3. Flanged fittings shall conform to AWWA C207.

7.6 Joints

7.6.1 PVC Pipe Joints

Joints, fittings, and couplings shall be as specified for PVC pipe. Joints connecting pipe of differing materials shall be made in accordance with the manufacturer's recommendations.

7.6.2 Ductile Iron Pipe Joints

1) Mechanical joints shall be of the stuffing box type and shall conform to AWWA C111.
2) Push-on joints shall conform to AWWA C111.
3) Rubber gaskets and lubricants shall conform to the applicable requirements of AWWA C111.

7.7 Gate Valves

Gate valves, ball valves, and standard hose bibbs will be the most common type of valves used for these projects. Gate valves should be used for the larger applications. Either gate valves or ball valves may be used for the smaller applications and hose bibbs or ball valves may be used for the point-of-service outlet. The use of ball valves is recommended as point-of-service outlets where very low pressure (less than approximately 10 psi) is available.

Gate valves shall be designed for a working pressure of not less than 150 psi. Valve connections shall be as required for the piping in which they are installed. Valves shall have a clear waterway equal to the full nominal diameter of the valve, and shall be opened by turning counterclockwise.

The operating nut or wheel shall have an arrow, cast in the metal, indicating the direction of opening.

1) **Valves less than 3 inches in diameter:** Valves less than 3 inches in diameter shall be all bronze and shall conform to MSS SP-80, Type 1, Class 150. Bronze body ball valves with stainless steel balls may be used in lieu of gate valves for this application. Hose bibbs shall be brass with straight or angle bodies with faucet handle securely attached to the stem. Faucet spout shall have 20 mm (3/4-inch) exposed hose thread. See Figure 7 - 3 for an example of a low-pressure service outlet (yard hydrant). For locations where higher pressure is available, similar details may be used substituting a hose bibb for the ball valve.

2) **Valves 3 inches in diameter and larger:** Valves 3 inches in diameter and larger shall be iron body, bronze mounted, and shall conform to AWWA C500. Flanges shall not be buried.

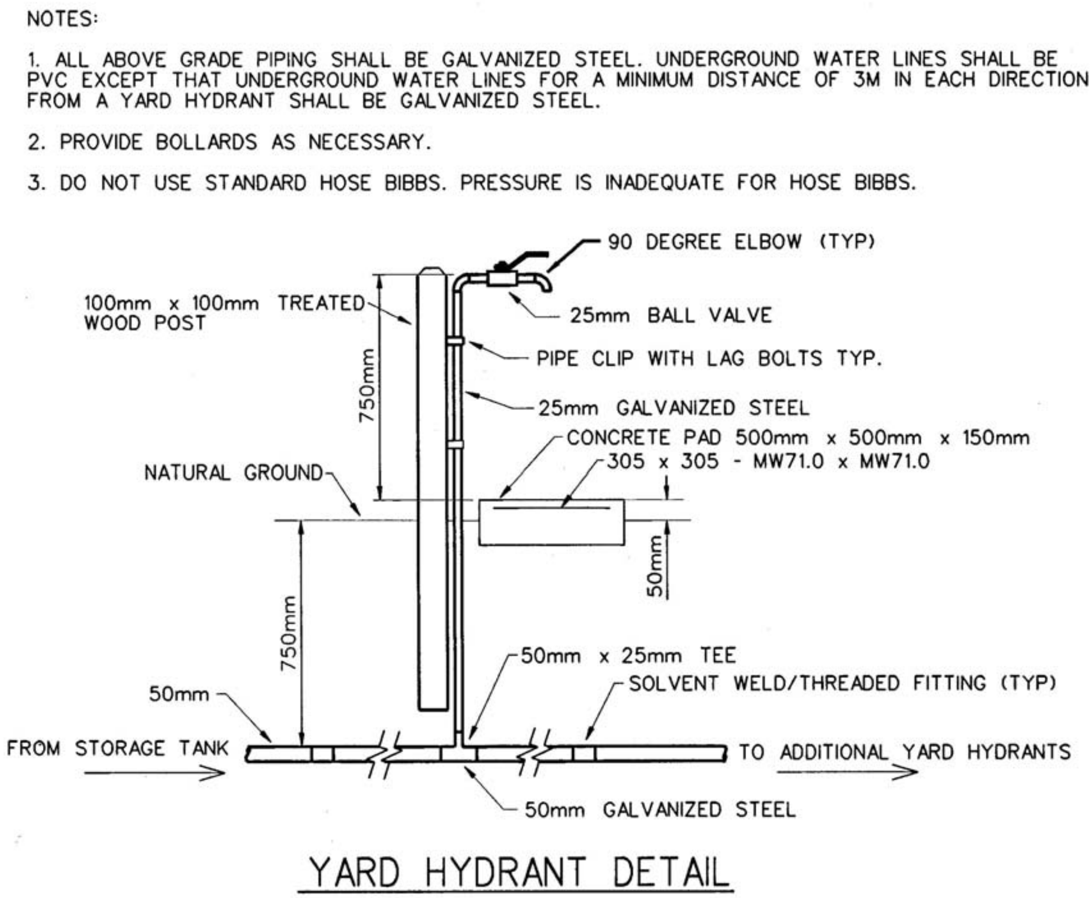

Figure 7 - 3 Typical Low Pressure Point-of-Service Outlet

7.8 Installation

7.8.1 Cutting of Pipe

Cutting of pipe shall be done in a neat and workmanlike manner without damage to the pipe. Unless otherwise recommended by the manufacturer, cutting shall be done with a mechanical cutter. A wheel cutter shall be used when practicable. Squeeze type mechanical cutters shall not be used for ductile iron.

7.8.2 Placing and Laying

Pipe and accessories shall be carefully lowered into the trench by means of ropes, belt slings, or other authorized equipment. Water-line materials shall not be dropped or dumped into the trench. Abrasion of the pipe coating shall be avoided. Pipe shall be laid with the bells facing in the direction of lying. The full length of each section of pipe shall rest solidly upon the pipe bed, with recesses excavated to accommodate bells, couplings, and joints. Pipe that has the grade or joint disturbed after lying shall be removed and re-installed. Pipe shall not be laid in water or when trench conditions are unsuitable for the work. Water shall be kept out of the trench until joints are complete. When work is not in progress, open ends of pipe, fittings, and valves shall be securely closed so that no trench water, earth, or other substance will be allowed to enter the pipes or fittings. Where any part of the coating or lining is damaged, the repair shall be made in a satisfactory manner. Pipe ends left for future connections shall be valved, plugged, or capped and anchored.

7.8.2.1 Plastic Pipe Installation

PVC pipe shall be installed in accordance with AWWA M23 and with the manufacturer's recommendations. Usually, the manufacturer will have an installation guide available. This guide should be followed should the AWWA Manual not be available.

7.8.2.2 Penetrations

Pipe passing through walls of valve pits (reinforced concrete valve boxes) and structures shall be provided with ductile iron or Schedule 40 steel wall sleeves. Annular space between walls and sleeves shall be filled with rich cement mortar. Annular space between pipe and sleeves shall be filled with mastic.

7.8.2.3 Flanged Pipe

Flanged pipe shall only be installed above ground or with the flanges in valve pits.

7.8.3 Jointing

7.8.3.1 PVC Plastic Pipe Jointing Requirements

1) **Pipe less than 4-inch diameter**: Threaded joints may be used with schedule 80 pipe only and shall be made by wrapping the male threads with approved thread tape or applying an approved lubricant, then threading the joining members together. The joint shall be tightened using strap wrenches to prevent damage to the pipe and/or fitting. To avoid excessive torque, joints shall be tightened no more than one thread past hand-tight. Preformed rubber-ring gaskets for elastomeric-gasket joints shall be made in accordance with ASTM F 477. Pipe ends for push-on joints shall be beveled to facilitate assembly and marked to indicate when the pipe is fully seated. The gasket shall be pre-lubricated to prevent displacement. The gasket and ring groove in the bell or coupling shall match. The manufacturer of the pipe or fitting shall supply the elastomeric gasket. Couplings shall be provided with stops or centering rings to assure that the coupling is centered on the joint. Solvent cement joints shall use sockets conforming to ASTM D 2467. The solvent cement used shall meet the requirements of ASTM D 2564; the joint assembly shall be made in accordance with ASTM D 2855 and the manufacturer's specific recommendations.

2) **Pipe from 4 to 12-inches in diameter**: Joints shall be elastomeric gasket as specified in AWWA C900. Jointing procedure shall be as specified for pipe less than 4-inch diameter above with configuration using elastomeric ring gasket.

7.8.3.2 Ductile Iron Pipe Jointing Requirements

Mechanical and push-on type joints shall be installed in accordance with AWWA C600 for buried lines or AWWA C606 for grooved and shouldered pipe above ground or in pits.

7.8.3.3 Galvanized Steel Pipe Jointing Requirements

Screw joints shall be made tight with a stiff mixture of graphite and oil, inert filler and oil, or with an approved graphite compound, applied with a brush to the male threads only. Compounds shall not contain lead.

7.8.4 Bacterial Disinfection

Each unit of completed waterline shall be disinfected as prescribed by AWWA C651 or as follows. After pressure tests have been conducted, the unit to be disinfected shall be thoroughly flushed with water until all entrained dirt and mud have been removed before introducing the chlorinating material. The chlorinating material shall be either liquid chlorine, conforming to AWWA B301 or calcium or sodium hypochlorite, conforming to AWWA B300. The chlorinating material shall provide a dosage of not less than 50 ppm and shall be introduced into the water lines. PVC pipelines shall be chlorinated using only the above-specified chlorinating material in solution. The agent shall not be introduced into the line in a dry solid state. The treated water shall be retained in the pipe long enough to destroy all non-spore forming bacteria. Except where a shorter period is approved, the retention time shall be at least 24 hours and shall produce not less than 25 ppm of free chlorine residual throughout the line at the end of the retention period. Valves on the lines being disinfected shall be opened and closed several times during the contact period. The line shall then be flushed with clean water until the residual chlorine is reduced to less than 1.0 ppm. From several points in the unit, USSOUTHCOM personnel shall take at least 3 water samples in proper sterilized containers and perform a bacterial examination in accordance with the local water authority's or USACHPPM's approved methods. USACHPPM or the host nation shall perform laboratory testing. The disinfection shall be repeated until tests indicate the absence of pollution for at least 2 full days. The system will not be turned over to the local community or water authority until satisfactory bacteriological results have been obtained.

Swimming pool kits should be used to test for chlorine residue. See the table located in Appendix E, page E - 3, Common Chlorine Solutions for Use in Well Drilling.

7.8.5 Cleanup

Upon completion of the installation of water lines and appurtenances, all debris and surplus materials resulting from the work shall be removed.

SECTION 8

OPERATION AND MAINTENANCE

EXECUTIVE SUMMARY

During the site selection and well development, coordination should be made with the community leaders and the local water authority. This coordination shall establish ownership of the well, responsibility for the water treatment system, the water storage, and the distribution system. The mission will not be complete until an operations and maintenance manual for the entire water system is provided in the host nation's language.

Due to lack of expertise and financial resources, long-term operation and maintenance of the new systems may be difficult or impossible for many communities. In these cases, the responsibility for system operation and maintenance should be turned over to the host nation's water authority.

8.1 Introduction

During the site selection and well development, coordination should be made with the community leaders and the local water authority. This coordination shall establish ownership of the well, responsibility for the water treatment system, the water storage, and the distribution system. The mission will not be complete until an operations and maintenance manual for the entire water system is provided in the host nation's language. Regardless of the type of system designed, the Operation and Maintenance Manual should follow the outline shown for Water Treatment Systems with inapplicable items omitted.

Due to lack of expertise and financial resources, long-term operation and maintenance of the new systems may be difficult or impossible for many communities. In these cases, the responsibility for system operation and maintenance should be turned over to the host nation's water authority.

Accurate and complete well drilling logs, well construction diagrams, pumping test results, and any other pertinent data obtained during the well drilling and installation operations are needed to be able to operate and maintain the water systems. This information should be included in the Operation and Maintenance Manual. Copies of the manual should be given to local water authority. Failing to supply the operators with sufficient well drilling and installation information can render a system useless. Without pumping test results, the operator will not be able to purchase and install the correct pump for the well. A pump that is too large may cause the water level in the well to drop below the screen, which can damage the pump and severely shorten the life of the well. Low water levels may also cause bacteria to grow in the well, thus clogging the screen or contaminating the water. Many other implications of improper turnover exist, but are too numerous to list here.

8.2 Wells with Hand Pumps

Water treatment will not be provided for locations where the well water meets all the water quality tests required by the local water authority and where a hand pump is to be provided. All documents provided with the hand pump shall be given to the local person and/or agency that will maintain the hand pump.

8.3 Wells Provided with Water Storage Tanks

In all cases where water storage is to be provided chlorination will be required as the minimum for water treatment. See Section 3.1 for further information. An operation and maintenance manual is required for all systems provided with water storage.

8.4 Operation and Maintenance Manual for Water Supply and Distribution Systems

Upon completion of the new water supply and distribution system, an operations and maintenance manual should be prepared and training provided to the operators.

A suggested outline follows:

- Section 1: Facility Overview
    - Introduction

- Objective and Purpose
- Design Criteria
- Supply and Distribution Goals
- Overview Drawing
- Overview Photo

- Section 2: Pump and Well Data
    - Accurate and complete well drilling logs, and any other pertinent data obtained during the well drilling and installation operations
    - Well construction diagrams, pumping test results
    - Water pump description, maintenance and operational instructions
    - Disinfection including equipment description, maintenance instructions, and operational procedures

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- Section 3: Storage
    - Storage tank description, maintenance and operational instructions

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- Section 4: Distribution Piping System Maintenance/Repair Procedures
    - Piping and Valve description, maintenance and operational instructions
    - Pipe breakage or leak repair procedures

- Section 5: Equipment Manuals
    - All materials supplied with pumps, valves, controls, and chlorination equipment. These manuals should include information on how to operate each piece of equipment, routine maintenance schedule, parts list, etc.

Under each of the main headings or sections, the following applicable subsections will be included:

- Purpose and Function,
- Design Criteria,
- Equipment Identification and Numbering,
- System Operating Procedures,
- Startup (manual),
- Shutdown (manual),
- Equipment Operating Procedures,
    - Startup (manual);
    - Shutdown (manual);
- Equipment Maintenance Manuals (provided by manufacturer), and
- Safety (as it applies to the section).

Training should be provided prior to turning over the water treatment system to the designated operators. The training will be “shoulder to shoulder” type training. The training will be a walk through where the purpose of each piece of equipment is explained, including controls system, and routine maintenance for each process.

8.5 Operation and Maintenance Manual for Water Treatment Systems

Upon completion of the new water treatment system an operation and maintenance manual should be prepared and training provided to the operators.

A suggested manual outline for the water treatment processes follows:

- Section 1: Facility Overview
  - ➢ Introduction
  - ➢ Objective and Purpose
  - ➢ Design Criteria
  - ➢ Treatment Goals
  - ➢ Overview Drawing
  - ➢ Overview Photo

- Section 2: Water Treatment Processes
  - ➢ Process Design Purpose
  - ➢ Process Descriptions (all that apply)
    - ✓ Raw Water Pumping
    - ✓ Slow Sand Filtration System
    - ✓ Disinfection – Primary and Secondary
    - ✓ Clearwell Storage
    - ✓ High Service Pumping
    - ✓ Chemical Addition
    - ✓ Solids Handling and Disposal

- Section 3: Equipment Manuals
  - ➢ All materials supplied with pumps, slow sand filtration units, and chlorination equipment. These should include information on how to operate each piece of equipment, routine maintenance schedule, parts list, etc.

Under each of the main headings or sections, the following applicable subsections will be included:

- Purpose and Function,
- Design Criteria,
- Equipment Identification and Numbering,
- System Operating Procedures,
- Startup (manual),
- Shutdown (manual),
- Equipment Operating Procedures,
  - ➢ Startup (manual);
  - ➢ Shutdown (manual);
- Equipment Maintenance Manuals (provided by manufacturer), and
- Safety (as it applies to the section).

Training should be provided prior to turning over the water treatment system to the designated operators. The training will be “shoulder to shoulder” type training. The training will be a walk through where the purpose of each treatment process is explained, including process controls, and routine maintenance for each process.

APPENDIX A

Glossary

Glossary

acute	Afflicted by a disease exhibiting a rapid onset followed by a short, severe course.
aeration	A process that promotes biological degradation of organic water. The process may be passive (as when waste is exposed to air) or active (as when a mixing or bubbling device introduces the air).
agar	A gelatinous material derived from certain marine algae. It is used as a base for bacterial culture media.
alum	A chemical powder containing sulfate formed of aluminium and some other element (esp. an alkali metal) or of aluminium used to treat water for drinking by settling materials that make water turbid.
amps	A commonly used term for amperes (electrical current).
appurtenances	Something added to another, more important thing; as an appendage to make it work properly or perhaps better.
aquifer	A formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs.
aquifer stress	Overpumping of an aquifer which can cause permanent damage.
auxiliary	Relating to something that is added but is not essential; "an ancillary electrical contact"; which allows a separate motor or unit of equipment to operate, without going through the primary electrical contact, hence a spare or additional contact.
available chlorine	The amount of chlorine present in a chemical compound.
backfill	Earth, soil, or gravel material used to refill an excavated area.
backwashing	Backward flow of water, as from the action of pumping water backwards through a sandfilter to washout foreign particulate matter.
butterfly valve	A valve used to accurately regulate the flow of water through a pipeline; a butterfly valve can be opened and closed slightly to regulate flow.
catchment area	An entire drainage area where rainwater or other precipitation eventually drains to the lowest point of common elevation.
chloramines	Compounds containing nitrogen, hydrogen, and chlorine, formed by the reaction between hypochlorous acid (HOCl) and ammonia (NH_3) and/or organic amines in water. The formation of

chloramines in drinking water treatment extends the disinfecting power of chlorine.

chlorination The application of chlorine or one of its compounds to water or wastewater, often for disinfection or oxidation purposes.

chlorine residual Amount of chlorine left over in water after the chlorine demand has been met; residuals may be as chlorines combined with ammonia nitrogen (CAC) or free available chlorine (FAC). FAC kills bacteria more rapidly than CAC.

cistern An artificial reservoir or tank used for holding or storing water or other liquids. Typically a tank, often underground, used for storing rain water collected from a roof.

clarification A process or combination of processes where the primary purpose is to reduce the concentration of suspended matter in a liquid.

clay Individual rock or mineral particles less than 0.002 mm in diameter.

coagulation The clumping of particles which results in the settling of impurities. It may be induced by coagulants such as lime, alum, and iron salts.

colloidal matter Substances made up of small particles that remain in suspension in water.

color comparator tester A plastic test kit, manufactured by companies that offer water testing is usually based on the color comparison of the sample related to standard colors on a rotating wheel. The wheel color closest to the sample's color indicates how much chlorine, for example, is present.

conditioning The chemical adjustment of water, for example, to get the desire clarity, purity, or sanitary condition.

contaminant An impurity which makes water unfit for human consumption or domestic use.

contamination Introduction of harmful substances including organisms and chemicals to a water supply; these substances may cause illness or disability.

deep well pump Any pump capable of pumping water from wells where the water is more than 10m below the ground surface.

desalination The purification of salt or brackish water by removing the dissolved salts.

discharge Quantity of flow.

disinfection	Destruction of harmful microorganisms present in water, through physical (such as boiling) or chemical (such as chlorination) means.
drawdown	The distance between the water table and the water level in a well during continued pumping.
drop pipe	The pipe in the well connecting to the pump.
E. coli	A bacillus *(Escherichia coli)* normally found in the human gastrointestinal tract and existing as numerous strains, some of which are responsible for diarrheal diseases.
effective size	The grain size in millimeters for a particle where 10% of the particles by weight are smaller and 90% are larger.
effluent	Solid, liquid, or gas wastes which enter the environment as a by-product of man-oriented processes. The discharge or outflow of water from ground or subsurface storage.
fecal coliform	Bacteria found in the large intestine; a coliform count is often used as an indicator of fecal contamination in water supplies.
ferrocement	An economical and simple-to-use type of reinforced concrete made of wire mesh, sand, water and cement.
flocculation	In water and wastewater treatment, the agglomeration or clustering of colloidal and finely divided suspended matter after coagulation by gentle stirring by either mechanical or hydraulic means such that they can be separated from water or sewage.
freeboard	The height of the sedimentation basin above the water level; it prevents water from overflowing and reduces disturbance by winds.
friction head	The pressure loss due to friction in a pipe.
friction losses	The energy required to overcome friction caused by pipe roughness, restrictions and changes in direction; usually expressed in meters of water or “head.”
gate valve	Refers to the operating mechanism for the valve, which is a sliding gate that moves up or down to block the flow. Often used as isolation valves. Never used as control valves. Because the gate slides, it is very subject to wear, and gate valves wear out fast when used often. Some gate valves use a wedge-shaped gate, which may hold up better.
gravel	Individual rock or mineral particles that range in diameter from the upper limit of sands (4.76 mm) to a diameter of 76 mm according to the Unified Soil Classification System.
gravity flow	Flow of water from high ground to low by natural forces.

groundwater	Water beneath the Earth's surface, often between saturated soil and rock, that supplies wells and springs.
growth medium	A liquid or gelatin which promotes the development of bacteria into colonies.
hand pump well	A well, designed to supply water for domestic use that is powered by a hand-drawn piston pump.
head	Difference in water level between the inflow and outflow ends of a water system.
helminth	A worm, especially a parasitic roundworm or tapeworm.
incubate	To cause bacteria to develop colonies by keeping them warm.
laterals	A lateral part, projection, passage, or appendage, such as a secondary pipe branching off the main branch.
manway	An opening to allow access for routine maintenance.
morbidity	The rate of incidence of a disease.
mortality	Death rate or death, especially of large numbers; heavy loss of life.
most probable number	An arithmetic method used by laboratories based on the results of a certain test techniques that require special test tubes.
multiple-barrier concept	The concept of providing more than one level of treatment for drinking water, such as filtration followed by disinfection which allows additional protection in case one of the treatments happens to fail.
multiple tube method	A water testing method used by laboratories for the expressed purpose of determining the presence of bacterial contamination, if any.
nutrient broth	A liquid which induces the development of bacteria colonies; a growth medium.
orthotolidine test	A chemical test for measuring chlorine in a water sample using a simple color comparator tester based on the degree of yellow color.
pathogens	Disease-causing bacteria.
peak demand	The greatest demand or need for water by the users; peak demands usually occur in the morning and late afternoon.
per capita	Per person.

petri dish	A shallow round transparent glass or plastic dish with an overlapping cover used for developing bacteria colonies in a growth medium.
pH	Hydrogen ion concentration: a measure of the acidity or basicity of a solution. A measure of the acidity or alkalinity or a solution, numerically equal to 7 for neutral solutions, increasing with increasing alkalinity and decreasing with increasing acidity. The pH scale commonly in use ranges from 0 to 14.
plumb bob	A usually conical metal weight attached to the end of a plumb line to determine accurate points of intersection or absolute vertical settings.
pollution (water)	The addition to a natural body of water of any material that diminishes the optimal economic use of the water body and has an adverse effect on the surrounding environment.
potable (potable water)	Describes water that does not contain objectionable pollution, contamination, minerals, or infective agents and is considered satisfactory for domestic consumption.
prefabricated	Equipment units that are built at a fabricators shop and need only assembly by a field crew.
prime	To put water in a pump to start it pumping.
pumping head	The height of water a pump produces when pumping; it includes the height of the highest point in the system plus the equivalent height to overcome friction; expressed as meters of water.
raw water	Untreated water that is to pass through a treatment system.
reconnaissance	An onsite visit to an area for placement of water systems for the purposes of collecting data to determine the suitability of the water source, protection and design requirements, and the applicable type of system needed to provide a water system.
reinforced concrete	Concrete containing steel reinforcing rods for extra strength.
remediate	The act or process of correcting a fault or deficiency. Treating water, for example, to remove the contamination that may have resulting from the presence of man.
reservoir	A pond, lake, basin or other space either natural or created that is used for storage, regulation, and control of water for a variety of uses.
roughing filter	A gravel/sand filter that is used to help reduce high turbidity levels in water upstream of a slow sand filter.

runoff	That portion of the precipitation in a drainage area that is discharged from the area in stream channels. Types include surface runoff, groundwater runoff, and seepage.
safe well yield	The pumping rate (yield) from a well that will not damage the aquifer or reduce the water level (in the well) below the pump intake.
sand-bitumen mixture	A sort of crude asphalt that is prepared by mixing a bitumen with sand.
sanitary survey	An extensive field evaluation of actual and potential conditions affecting the acceptability of all available water sources.
schmutzdecke	A German word meaning a layer of biologically active microorganisms that forms on the top of a filter bed; the microorganisms break down organic matter and kill bacteria in water.
sedimentation	The act or process of depositing sediment. In water treatment, it usually is associated with tanks or vessels that hold water for a quiescent period (hours, days, or weeks) allowing heavier suspended material to settle.
shallow well pump	Any pump, which cannot pump from depths of over 10m below the level of the pump.
sight feed glass	A viewing glass used to assess how much chlorine solution is being added to a water treatment system.
siphoning	Drawing off or conveying through a pipe or tube that is fashioned or deployed in an inverted U shape and filled until atmospheric pressure is sufficient to force a liquid from a reservoir in one end of the tube over a barrier higher than the reservoir and out the other end.
slow sand filtration	The action of passing water slowly through a series of granulated sands to allow biological, chemical, and physical reactions to occur for the removal of contaminates that may be harmful to man.
specials	Components of a piping system other than the pipe and fittings. Couplings are an example.
standard plate count	A testing method used by laboratories to determine the degree of coliform bacteria contamination.
static head	The difference in meters between the elevation of the pump and the highest point in the system, usually the top of a storage tank, to which the pump must raise water. The pressure loss (or gain) due to differences in elevation.
static lift	The pressure loss due to differences in elevation.

static water level The water level in a well when the pump is not operating.

stratified To form, arrange, or deposit in layers.

sucker rod The rod, which connects a windmill or hand pump to the pump cylinder in the well.

suction lift The difference in elevation between the inlet (suction) side of a pump and the water level in the well when the pump is pumping plus friction losses; expressed in meters of water.

superchlorination The addition of excess amounts of chlorine in order to provide complete disinfection of a water storage well, tank, or piping system beyond the amount normally required for safe disinfection. It is used to because some settled-out materials and excessive growths of bacteria are not effectively destroyed at normal 1 to 2 parts per million levels of chlorine in the drinking water. It is employed periodically to insure disinfection within the system, but not frequently because the overuse of chlorination material is wasteful and expensive.

swale A shallow trough-like depression that carries water mainly during rainstorms or snow melts.

tee chlorinator A special piping tee for use with a chlorinator where chlorine tablets are placed through a screw top tee and secured in the water flow.

total dynamic head (TDH) The total energy, which the pump must provide to lift water to the pump, to raise water to the maximum elevation, and to meet all friction requirements; expressed in meters of water.

turbid Stirred or disturbed, such as sediment; not clear or translucent, being opaque with suspended matter, such as a sediment-laden stream.

underdrains The collective drainage system of pipes or bricks usually under a filter media that conducts water to its next or subsequent treatment process after it flows through the media.

vacuum A pump used to pull or push water through a filter in the membrane filter technique of bacteriological analysis of water.

water hammer Water hammer is transient pressure or surge pressure caused by abrupt changes in momentum of a column of water. Abrupt changes in momentum are commonly caused by sudden valve closure or pump start or stoppage.

watershed The division between regions draining rainwater or snowmelt into a river, river system, or other body of water.

water treatment A process in which impurities such as dirt and harmful materials are removed from water.

weir	A barrier placed in moving water to stop, control or measure water flow.
well head	That portion of a water well system that rest above ground and prior to burial on the way to a storage system, which may include tanks, pipes, valves, chorine feed tanks, etc.

APPENDIX B

Useful Measurement Conversion Tables

atmosphere **atm**
76 centimeters of mercury at 0ºC
29.92 inches of mercury at 0ºC
406.8 inches of water at 4º C
14.7 pounds per square inch

centimeter **cm**
0.010 meters
0.3937 inches

cubic centimeter **cm^3**
0.000001 cubic meters
0.06102 cubic inches
0.00003531 cubic feet

cubic foot **ft^3**
1728 cubic inches
0.0282 cubic meters
7.481 gallons
28.32 liters
62.4283 pounds of water

cubic inch **in^3**
16.39 cubic centimeters
0.0005787 cubic feet
0.00001639 cubic meters

cubic meter **m^3**
1,000,000 cubic centimeters
35.31 cubic feet
61023 cubic inches
264.2 gallons

degree (arc) °
60 minutes
3600 seconds
0.01745 radians

foot **ft**
12 inches
0.333 yards
0.30481 meters
0.004329 gallons

foot-pound **ft-lb**
0.001285 Btu
1.356 joules

foot of water **(n/a)**
0.0295 atmospheres
62.43 pounds per square foot
0.4335 pounds per square inch
2.242 centimeters of mercury

(n/a) not applicable

gallon **gal**
0.1337 cubic feet
231 cubic inches
3.785 liters
8.336 pounds of water

gallons per minute **gpm**

grain **grain**
0.06481 grams
0.002286 ounces

gram **g**
15.43 grains
0.03527 ounces
0.002205 pounds

gravity ***g***
32.1740 feet per second per second
980.665 centimeters per second per second

horsepower **HP**
550 foot-pounds per second
33,000 foot-pounds per minute
42.41 Btu per minute
745.7 watts

inch **in**
0.08333 feet
2.54 centimeters

inch of water **(n/a)**
0.002458 atmospheres
5.204 pounds per square foot
0.03613 pounds per square inch
0.1868 centimeters of mercury

kilogram **kg**
1000 grams
2.2046 pounds
35.274 ounces

kilometer **km**
1000 meters
0.6214 miles

kilowatt **kw**
1.341 horsepower
44,257 foot-pounds per minute
56.89 Btu per minute

liter **L**
0.001 cubic meter
1.057 quarts
0.2642 gallons
0.03531 cubic feet

meter **m**
- 100 centimeters
- 1,000 millimeters
- 39.37 inches
- 3.2808 feet

micron **µ**
- 0.001 millimeters
- 10,000-Angstrom units
- 39.37 millionths of an inch

micro inch **µin**
- 0.000001 inches
- 0.0254 microns

mil **mil**
- 0.001 inches
- 25.4 microns
- 0.0254 millimeters

mile **mi**
- 5280 feet
- 1760 yards
- 1.609 kilometers

miles per hour **mph**
- 1 mph = 1.467 feet per second
- 1 mph = 88 feet per minute
- 1 mph = 44.7 centimeters per second

ounce **oz**
- 0.0625 pounds
- 28.35 grams
- 437.5 grains

pound **lb**
- 16 ounces
- 0.4536 kilograms
- 7000 grains
- 1.2153 pounds Troy

pounds per square inch **psi**
- 0.06804 atmospheres
- 5.171 centimeters of mercury
- 27.68 inches of water

quart **qt**
- 2 pints
- 0.25 gallons
- 0.9464 liters
- 2.084 pounds of water

radian **radian**
- 57.296 degrees
- 57º17'44.81"
- 360º2

square centimeter **cm^2**
- 0.0001 square meters
- 0.155 square inches

square foot **ft^2**
- 144 square inches
- 0.0929 square meters

square inch **in^2**
- 6.452 square centimeters
- 1,273,240 circular mils

square meter **m^2**
- 10000 square centimeters
- 10.764 square feet
- 1.196 square yards

watt **w**
- 44.26 foot-pounds per minute
- 0.001 kilowatts
- 0.00134 horsepower

APPENDIX C *

Worksheets

* These worksheets are from USAID Water for the World Technical Notes.

Worksheet A. Suggested Record Form for Field Data Relevant to Water Samples

Agency or person requesting sample:			Sample No.		
Reason for sample:	☐	Routine	☐	For Bacteriological Analysis	
	☐	For Other Analysis	☐	For Physical/Chemical Analysis	
	☐	Specific (explain)			
Date and hour of sampling:					
Sample Location:	Town:				
Sample Source	☐	Tap	☐	Well	☐ Other (specify)
	☐	Rain Catchment	☐	Stream	
	☐	Cistern	☐	Pond	
Exact spot from where sample was drawn:					
Raw water acuree:					
Is water treated?	☐	No	☐	Yes (If yes, specify type of treatment.)	
Does water quality change after heavy rain?	☐	No	☐	Yes (If yes, explain: odor, color, taste, turbidity.)	
If sample is drawn form a well, specify:					
	Depth of well				
	Distance from water surface to ground level				
	Covered or uncovered well				
	Type of cover, materials, condition of cover				
	Is well newly constructed or recently altered or repaired (explain)				

Worksheet A. Suggested Record Form for Field Data Relevant to Water Samples, (Continued)

	Method of raising water (pump, rope and bucket, etc.)
	Does the well have a protective apron
	Type, material, size and condition of apron
	Well lining material
	Possible sources of contamination
If sample is drawn from a spring, specify:	
	Is sample drawn directly from spring or collection box
	Construction materials and condition of collection box
If sample is drawn from a stream or river, specify:	
	Depth the sample was drawn
	Was sample drawn from a boat
	Possible sources of contamination
Length of time sample was stored before analysis	
Temperature at which sample was stored	

Worksheet B. Calculating Quantities needed for a Concrete Sedimentation Basin

Total volume of each rectangle = length (l) x width (w) x height (h)

1. Volume of two sides = ***4*** m x ***2*** m x ***0.25*** m x 2 = ***4*** m^3
2. Volume of two ends = ***1.5*** m x ***2*** m x ***0.25*** m x 2 = ***1.5*** m^3
3. Volume of foundation = ***4.5*** m x ***0.25*** m x ***1.5*** m = ***1.70*** m^3
4. Total volume of steps 1, 2, and 3 = ***7.2*** m^3
5. Add 10 % to cover extra height due to slope of bottom = ***.8*** m^3
6. Total volume of structure from steps 4 and 5 = ***8.0*** m^3

Volume of inlet structure

7. Volume of bottom ***0.3*** m x ***0.25*** m x ***1.5*** m = ***.11*** m^3
8. Volume of side ***1.5*** m x ***.75*** m x ***0.25*** m = ***0.28*** m^3
9. Total volume of steps 7 and 8 = ***.4*** m^3

Volume of outlet structure

10. Volume of bottom ***0.3*** m x ***0.25*** m x ***1.5*** m = ***.11*** m^3
11. Volume of side ***1.5*** m x ***.55*** m x ***0.25*** m = ***0.20*** m^3
12. Total volume of steps 10 and 11 = ***.31*** m^3
13. Total volume from steps 6, 9, and 12 = ***8.71*** m^3
14. Unmixed volume of materials needed = total volume from step 13x1.5 = ***8.71*** m^3 x 1.5 = ***13.1*** m^3
15. Volume of each material (cement, sand, gravel 1:2:3)

    Cement: 0.167 x volume from line 14 ***13.1*** m^3= ***2.2*** m^3

    Sand: 0.33 x volume from line 14 ***13.1*** m^3= ***4.3*** m^3

    Gravel: 0.5 x volume from line 14 ***13.1*** m^3= ***6.6*** m^3
16. Number of 50 kg bags of cement = $\frac{\text{volume of cement}}{\text{volume per bag}}$

    $$\frac{\text{volume of cement}}{\text{volume per bag}} = \frac{\mathbf{2.2}\ m^3}{.033\ m^3/\text{bag}} = \mathbf{67}\ \text{bags}$$
17. Use about 28 liters of water for every bag of cement.

    Amount of water = 28 liters x ***67*** bags = ***1.876*** liters

NOTE: To save cement, a 1:2:4 mixture can be used with no loss of strength.

Worksheet C. Calculating Material Quantities for a Concrete Slow Sand Filter

Total volume of each rectangle = length (l) x width (w) x height (h)

1. Volume of two sides = ***1.75*** m x ***0.25*** m x ***3.1*** m x 2 = ***11.625*** m^3
2. Volume of two ends = ***3.5*** m x ***0.25*** m x ***3.1*** m x 2 = ***5.245*** m^3
3. Volume of foundation = ***8.0*** m x ***3.5*** m x ***0.25*** m = ***7.0*** m^3
4. Total volume of steps 1, 2, and 3 = ***24.0*** m^3
5. Add 10 % for safety factor = ***2.5*** m^3
6. Total volume of structure from steps 4 and 5 = ***26.56*** m^3
7. Unmixed volume of materials needed, total volume from step 6 x 1.5 = ***26.5*** x ***1.5*** = ***39.75*** m^3
8. Volume of each material (cement, sand, gravel, 1:2:3)

   Cement: 0.167 x volume from line 7 ***39.75*** = ***6.7*** m^3

   Sand: 0.33 x volume from line 7 ***39.75*** = ***13.15*** m^3

   Gravel: 0.5 x volume from line 7 ***39.75*** = ***19.9*** m^3
9. Number of 50 kg bags of cement = $\frac{\text{volume of cement}}{\text{volume per bag}}$

   $$\frac{\text{volume of cement}}{\text{volume per bag}} = \frac{6.7 \text{ m}^3}{.033 \text{ m}^3\text{/bag}} = 203 \text{ bags}$$
10. Use about 28 liters of water for every bag of cement.

    Amount of water = 28 liters x ***203*** bags = ***5684*** liters

NOTE: To save cement, a 1:2:4 mixture can be used with no loss of strength.

APPENDIX D
Commercial Slow Sand Filter Systems

APPENDIX D.1

Davnor Water Treatment Technologies, Ltd.

Groundwater System

Installation, Operation and Maintenance Manual

THE FOLLOWING INFORMATION IS USED BY PERMISSION OF DAVNOR WATER TREATMENT TECHNOLOGIES, LTD.

Davnor Water Treatment Technologies Ltd.
4007 23rd St. N.E.
Calgary, Alberta
Canada, T2E 6T3
Email: davnorinfo@davnor.com

Tel: (403) 219-3363

Fax: (403) 219-3373

TREATMENT SOLUTIONS

Water Treatment Solutions To Water Treatment Problems

The Davnor Approach to Water Treatment

Davnor Water Treatment systems are capable of treating water from surface supplies, groundwater, rainwater and municipal supplies to potable water (drinking water) standards. Systems are sized to meet all needs to simply drinking water needs. Davnor Water Treatment Systems are available to treat both rural and urban water supplies. If required Davnor Water Treatment Systems may incorporate traditional treatment technologies (softeners, reverse osmosis, distillation units, aeration, multi-media pressure filters, chemical disinfection, chemical coagulation aids, flocculation chambers, sedimentation basins, rapid sand filters, ultra violet disinfection, carbon filters and chemical addition if required by local regulatory agency or deemed essential to achieve treatment objectives), which meet Davnor's stringent quality and performance requirements. **Davnor Treatment Systems frequently benefit from the use of Davnor's own BioSand Water Filter technology**.

Water Treatment Problems

1. Surface Water Supplies

Water taken from surface supplies such as lakes, rivers, ponds, and dugouts may contain:

- Giardia, Cryptosporidia and other parasites.
- Bacteria, viruses including fecal coliform bacteria.
- Algae.
- Macro living and dead organic matter (e.g. leaves, large insects, etc.)
- Silt and other types of suspended sediments resulting in high turbidity.
- Color, taste and odor and other forms of objectionable dissolved organic matter usually from decaying vegetation in or adjacent the water supply or contained in surface runoff from surrounding watershed.
- Organic toxins (e.g. toxins from blue green algae, pesticides, herbicides, PCBs and other industrial waste).
- Inorganic toxins (e.g. mercury, arsenic, lead, industrial waste).
- Dissolved substances such as sodium, sulphates, fluoride and nitrates in objectionably high concentrations (normally less than deep wells).
- Hardness due to high concentrations of calcium and magnesium (normally less than deep wells).

2. Groundwater Supplies

Groundwater from shallow wells, deep wells and springs may contain:

- Bacteria, viruses including fecal coliform bacteria.
- Silt and sand (usually a result of inadequate well construction and development).
- Color, taste and odor and other forms of objectionable dissolved organic matter such as trihalomethane.
- Objectionable gases such as hydrogen sulfide and methane.
- Organic and inorganic toxins.
- High concentrations of dissolved solids such as sodium, fluoride, nitrates, sulphates etc.
- Hardness due to high concentrations of calcium and magnesium.
- Iron causing rust stains and metallic tastes.
- Manganese causing black stains and metallic tastes.
- Slimy deposits of iron bacteria and sulfide bacteria.

3. Rainwater

Rainwater collected from the roof of a building may contain:

- Silt and other types of suspended sediments washed off the surface of the roof and rinsed out of the eave troughs and downspouts.
- Macro living and dead organic matter.
- Parasites, bacteria and viruses from animal droppings and wind blown materials.
- Color, taste and odor resulting from decaying organic matter rinsed off the roof into the storage reservoir.

Toxins, which leach from roofing systems or deposited on roofs themselves.

4. Treated Water from Cities and Town Water Distribution Systems

Municipal water is typically treated to a quality safe for human use and consumption WHO standards slightly modified to consider local concerns). Despite the thoroughness with which the water may be treated, consumers continue to identify concerns regarding the quality of the water. These include:

- Risk of parasite contamination and other pathogens (lack of disinfection residual).
- Objection to chlorine and the presence of trihalomethane.
- Objection to fluoride, which has been added to the drinking water for management of tooth decay in children.
- Objectionable hardness.
- Objection to taste.
- Occasional presence of suspended particles.

In many parts of the world this list may be expanded to include all the concerns typical of untreated surface water.

APPENDIX D.2

Blackburn & Associates

Modular Polyethylene Slow Sand Filters

Blackburn & Associates

Modular Polyethylene

Slow Sand Filters

Installation
And
Maintenance

Blackburn & Associates

P.O. Box 37, The Sea Ranch, California, 95497

707 785 3986 * fax 208 723 5986

www.slowsandfilter.com

tec@slowsandfilter.com

How the slow sand filter Works

Slow sand filtration is primarily a biological process that works much the way a riverbank does. A column of water slowly (0.1 gal/ft^2) passes through a 3 ft layer of fine sand. At the top of the sand, an intense layer of microbial organisms naturally develops. This layer lives on whatever is passing through in the water. This layer, called the schmutzdecke, is responsible for removing up to 99.99% of all bacteria, viruses, Giardia, Criptosporidium, and parasites through predation. As the water passes through the deeper layers, other processes such as sedimentation, mechanical filtration, and electrical attraction remove still more. The result is that slow sand filters may be the best stand-alone water filters known.

Slow sand filters are recognized as a superior technology by the USEPA, the World health Organization, and enjoy widespread use in the U.S., Europe, and developing countries.

System requirements

Location: The slow sand filter should be located on a concrete slab, prepared and compacted earth site, or bed of pea gravel. The best location is between a spring source and a storage tank, however many other possible arrangements are possible (see fig.1).

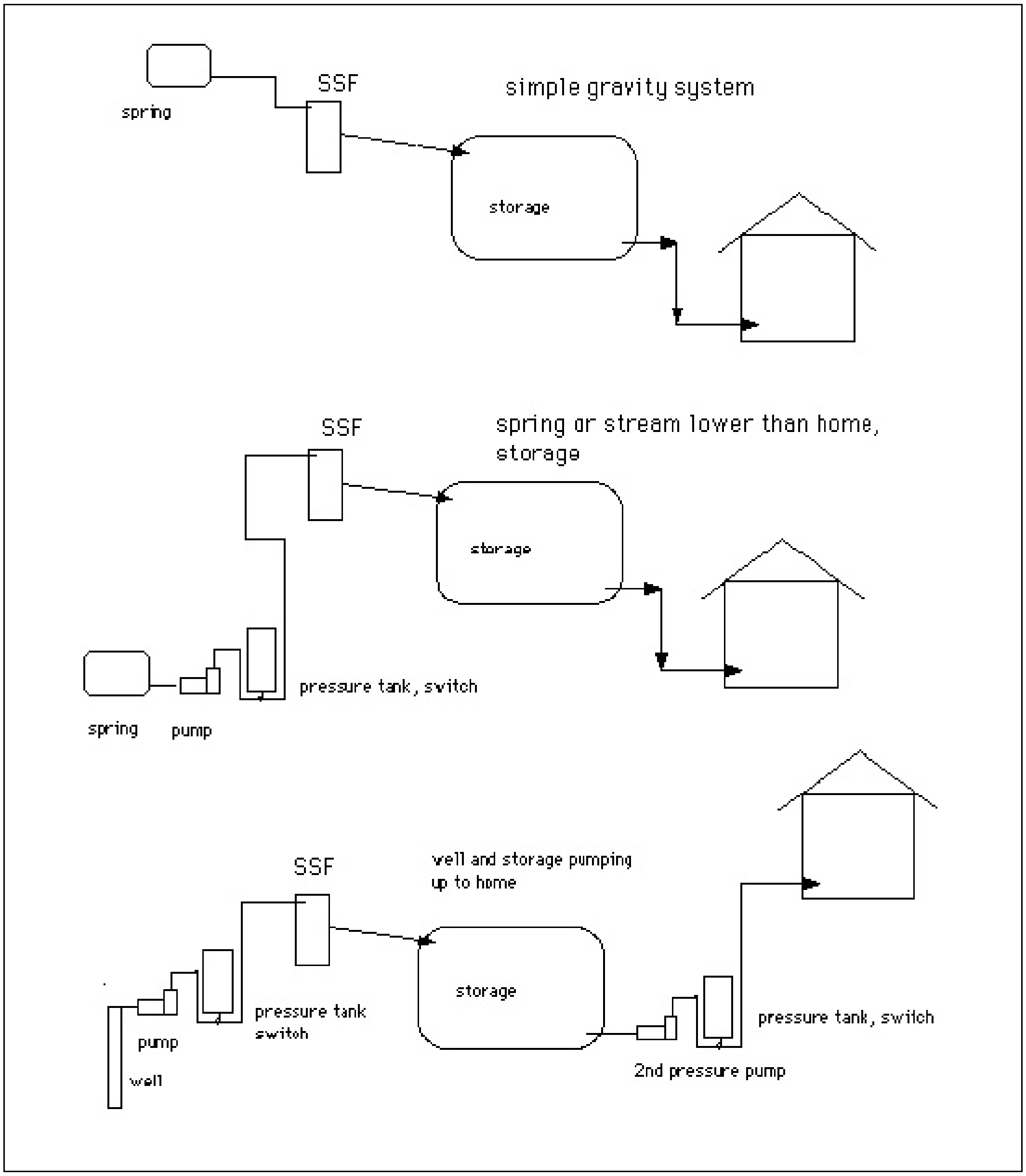
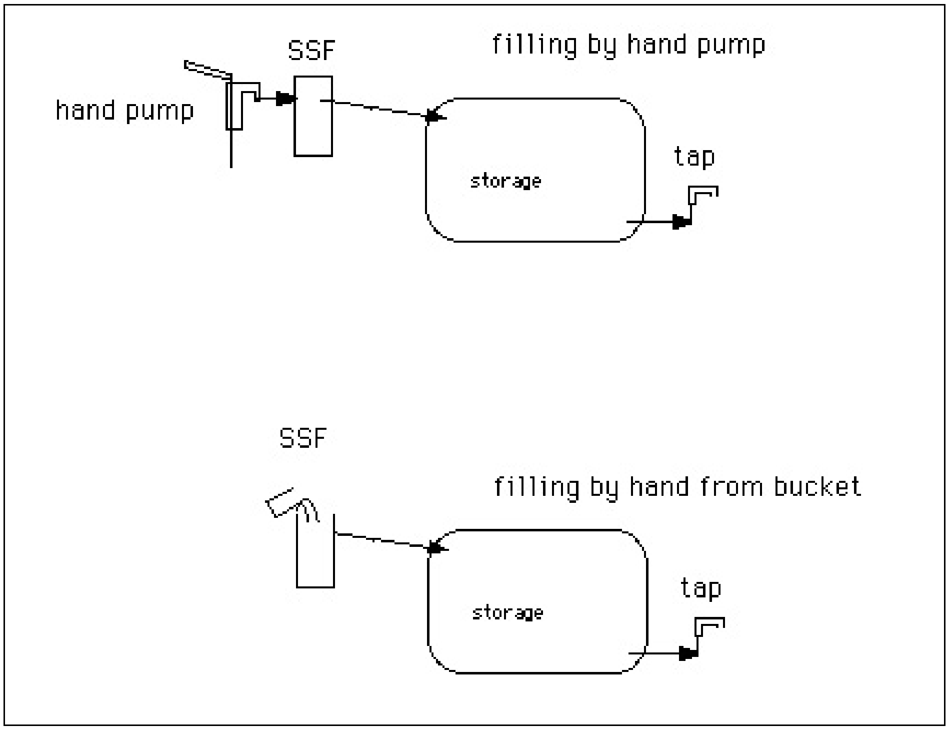


Figure 1. Slow sand filter arrangement



Storage

The slow sand filter has a normal peak design output 0.1 gpm/ft^2. The filter is designed to run continuously at this slow rate, and therefore requires storage of the filtered water to accommodate peak usage. Storage should be able to handle peak demand periods.

Raw Water Quality

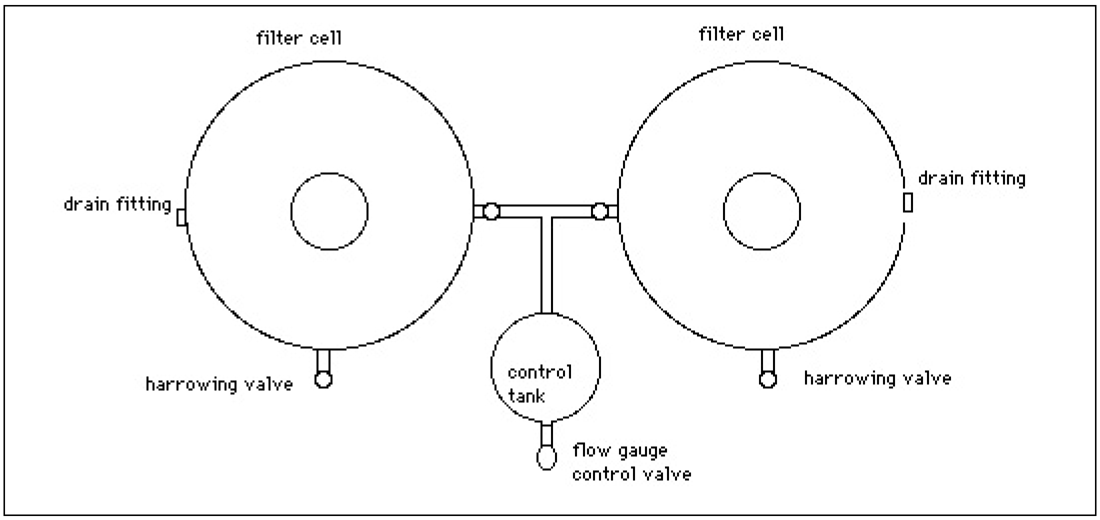
Slow sand filters are very good at removing turbidity (cloudiness) and bacteria. However, too much turbidity may cause the filter to clog prematurely. We recommend a maximum turbidity of the raw water at no more than 20 ntu for continuous use. The filter can tolerate higher turbidities for short periods, however. If your raw water is very cloudy and has substantial suspended solids, you should install a sediment tank and/or a roughing filter ahead of the slow sand filter. If you have questions about raw water quality, call Blackburn and Associates 707-785-3986 or email to tec@slowsandfilter.com for recommendations.

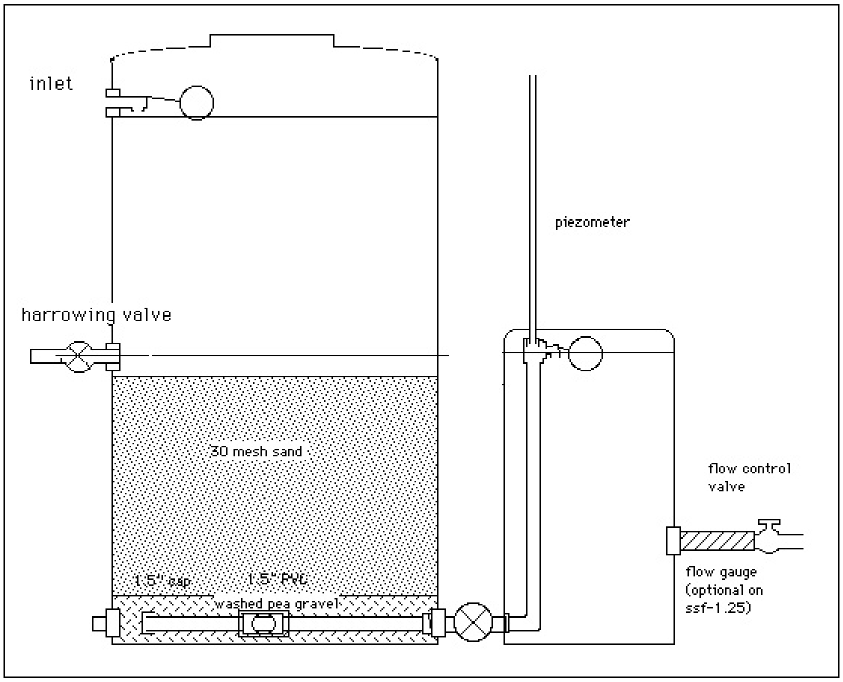
Installation

Site preparation. Locate the slow sand filter on a well-compacted, stable site such that the outlet from the filter is above the inlet to the storage tank. The filter may be placed on compacted soil, a concrete slab, or a bed of pea gravel. Do not place filter cells on a sand base. Sand can wash away during heavy rains and lead to uneven settling.

- **Plumbing connections**

  Connect the raw water source to the two filter cell float valves located on the upper side walls of the filter vessels near the two round small access ports. Position the tanks so that the outlets of the two tanks face each other. Install the male adapters, ball valves, and tee fitting as shown. Place the control tank so that the outlet of the tee faces the inlet of the control tank. Make this connection as shown. Install the threaded PVC nipples and threaded ball valves in the harrowing fittings as shown. Connect the 1-inch ball valve and flow gauge from the center control tank to the pipe going to storage. Make sure flow gauge is installed with arrow in direction of flow- from slow sand filter system to your storage tank. Install a tee on this pipe to relieve pipe of trapped air if necessary. Remove the plugs from the bottom fittings on the outside of the filter cells. Replace these with threaded PVC bushings and hose bibs or fittings connected to a waste line. These fittings will allow draining of the filter cell, running to waste of water during ripening or immediately after harrowing, and filling of the filter from the bottom up with filtered water to eliminate trapped air in the filter. Take care to make sure that cross-connections of wastewater to filtered water cannot occur. Install and/or adjust floats for filter cells (1 each) and for center tank (beneath access lid).





- **Loading the filter**

  Now that the filter is connected on its site, media loading can be initiated. On SSF-1.25 through SSF-6, remove the screw down lid on top of filters. For SSF-10, remove the top section by removing screws. Start by adding washed pea gravel to each filter cell. Make sure that the gravel is level and covers the pipes in the bottom of the filter. Next comes the sand. Add sand until two inches below harrowing bulkhead fittings. The specs at the end of this document show how much sand each filter size uses. When the sand is loaded, rake the top surface level. This completes filter loading. Finally, place a 12-inch (approximate) square concrete or ceramic tile on sand beneath inlet float valve to act as a splash plate.

- **Start-up**

  Initial filling of the filter should be accomplished by attaching a hose to the hose bibs attached to the drain fittings on the filter vessels and filling slowly. This eliminates air bubbles that can be trapped when filling is accomplished from above the sand bed. After initial filling and after maintenance, the filter is started by simply opening the inlet valves and filling the filter from above. It is a good idea to run the first water through he filter to waste because it may have dust from the sand and because the filter needs some time to ripen. Running water to waste is accomplished by opening the hose bibs in the bottom fittings and draining the water away at a rate of no more shown in specs for the filter used. Adjust using the flow gauge provided or, you can measure this with a bucket and a watch. It is recommended that safety chlorination disinfection of the distribution lines and tanks be initiated prior to using the system. Remove the dome lid of the center control tank. Chlorine bleach sufficient to leave a measurable residual in the entire distribution system should be added to the center control tank of the slow sand filter once water is flowing through the system. Replace dome lid. The precise amount of bleach to add is dependent upon storage volume and organic materials contamination of tanks, pipes, and fittings. A residual free chlorine level of 2 to 5 ppm should be sufficient.

Flow is regulated by setting the control valve. It is the 1-inch ball valve emerging 12 inches up from the bottom of the front of the center control tank. Where this valve is set depends on your usage. Open the valve and observe the flow gauge, or measure flow with a 1 gallon bucket and watch. Open or close the valve to obtain flow not exceeding specification for the filter used. If there may be a problem with personnel inadvertently changing this valve setting, remove the handle of the valve and place it in a secure place.

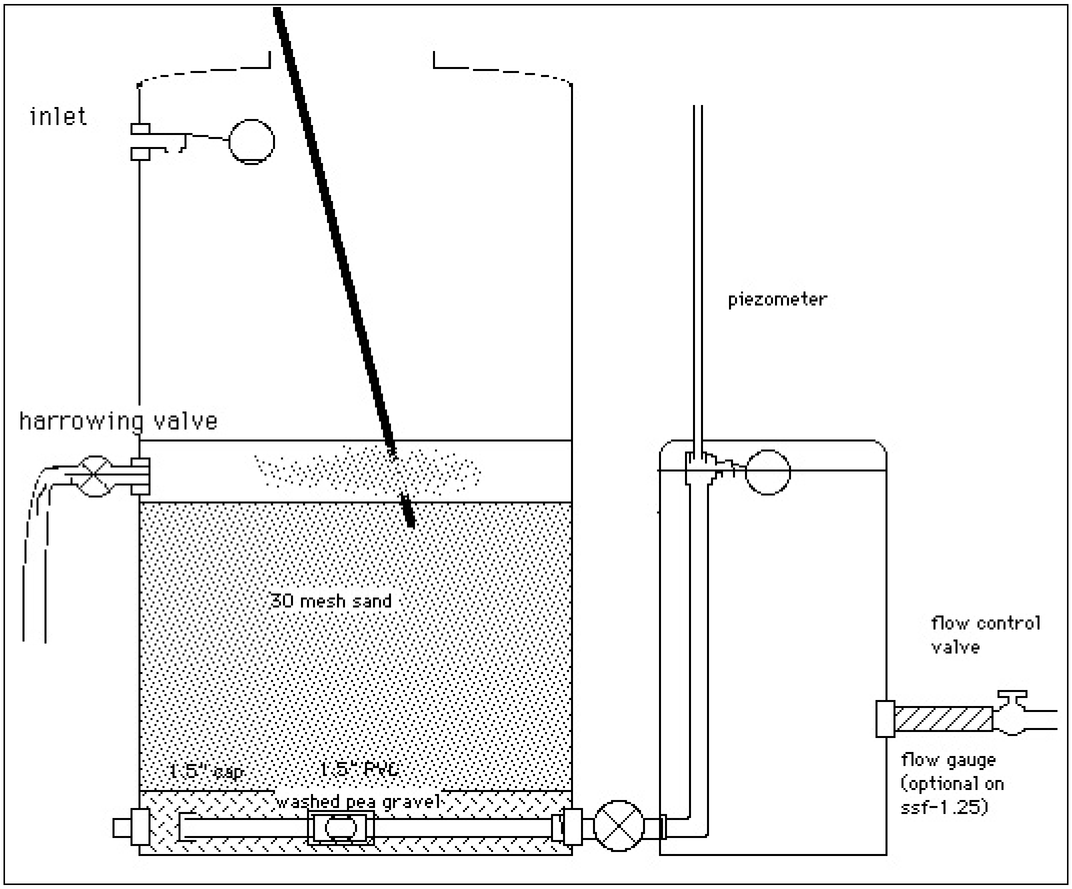
A ripening period is necessary for full performance of the biological layer of the filter to be achieved. This is variable depending on raw water quality, season, and temperature. Water testing for microbial quality of finished water is recommended prior to use for drinking water.

- **Maintenance**

The clear site-tube emerging from the small control tank tells you the operational condition of the filter. This tube, called a piezometer, indicates the pressure loss in the filter. As the filter begins to clog from buildup of suspended solids, the water level in the tube will drop even though the filter vessels are full. When water is no longer visible in the tube, but the filter vessels are full, it is time to service the filter.

- **Wet harrowing**

The filter is returned to proper operating condition by wet harrowing. The valves placed a little over halfway up the filter vessels are used for harrowing the filter. First, cutoff the water entering the filter through the float valve. Next, open the harrowing valve by rotating the handle one-quarter turn. This will begin to drain the standing water above the sand. Open the lid of the filter vessel. With a rake, piece of rebar, digging fork, or other pointed object; stir the top layer of the sand vigorously 2 to 3 inches deep. Continue to stir the sand until the water has drained off from above the sand. You will notice large amounts of silt and other fine material are being drained away. You may now shut the lid on the filter, re-close the harrowing valve, and return the filter to normal operation. If the water needs continued cleaning, open the valve at the float valve allowing water to enter the filter tank while continuing to rake and drain off through the harrowing valves. It is important to not let the top layer of the sand be exposed to air for long. This can damage the biological layer and effect filter performance. If raw water quality is pretty good, you can alternate harrowing the filters in a regular schedule of maintenance. If raw water quality is marginal, it is recommended that both filters be harrowed at the same time.



Sand replacement

At some point after 5-10 years, it may be necessary to remove the sand and wash or replace it. You will need to drain one cell or the other to do this. Draining a filter cell is accomplished by closing the 1.5 inch valve on the filter outlet. The filter drain faucet is then opened and the filter cell drained. Remove sand. It is best to do this on a cool morning. Once the sand and gravel are removed, the filter may be cleaned with fresh water, refilled with media as in installation above, and restarted.

Troubleshooting

The slow sand filter is a remarkably simple to install and operate machine, and there are not a lot of things to go wrong. However:

Dirty water emerging from filter at start-up	Improperly washed sand installed
No flow	Check piezometers, harrow filter if piezometer water level is more than 18 inches below level in filter tanks
Still no flow	Check float valve or control valve for obstruction
Water going through filter, but not reaching storage tank	Check for air lock. Install tee to release air from pipeline between filter and storage.
Frequent cleaning required (more often than 4 week intervals)	Harrow 2 to 3 inches into sand bed. If water is very cloudy, install gravel pre-filter or sedimentation tank

Specifications

SSF-1.25 Specifications

1.25 gpm
0.1 g/ft^2/min maximum loading rate
linear polyethylene 48 inches wide x 79 inches high
control tank, linear polyethylene, 29 inches wide x 49 inches high
sand - 32 ft^3 per cell 0.35 mm effective size, $U_c < 3$
underdrain gravel - 6 ft^3 3/8-inch pea gravel per cell

SSF-3 Specifications

1.25 gpm per cell, 2.50 gpm total, 3,619 gpd two cells total.
Minimum 2 cells, additional cells may be manifolded.
0.1 g/ft^2/min maximum loading rate
cells, linear polyethylene 48 inches diameter x 79 inches high
control tank, linear polyethylene, 29 inches wide x 49 inches high
effluent filter control, flow gauge (optional) and brass ball valve.
Piezometers to indicate head-loss in system
sand - 32 ft^3 per cell .35 mm effective size $U_c < 3$
underdrain gravel- 6 ft^3 3/8-inch pea gravel per cell

SSF-4 Specifications

2.2gpm per cell, 4.4 gpm total, 6,336 gpd two cells total.
Minimum 2 cells, additional cells may be manifolded.
0.1 g/ft^2/minute maximum loading rate
cells, linear polyethylene 64-inch wide x 79-inch high
control tank, linear polyethylene, 29 inches wide x 49 inches high
sand - 67 ft^3 per cell 0.35 mm effective size $U_c < 3$
underdrain gravel - 11 ft^3 3/8-inch pea gravel per cell

SSF-6 Specifications

2.82 gpm per cell maximum flow, 5.65 gpm total, 8,136 gpd two cells total.
Minimum 2 cells, additional cells may be manifolded.
0.1 g/ft^2/min maximum loading rate
cells (2), linear polyethylene 72 inches wide x 85 inches high, UV stabilized, NSF rated
control tank, linear polyethylene, 29 inches wide x 49 inches high
wet harrowing
external piezometer for measuring headloss
Flow gauge, brass metering valve for setting flow rate
Brass float valves for maintaining tank water levels
sand - 85 ft^3 per cell 0.35 mm effective size $U_c < 3$
underdrain gravel- 14 ft^3 3/8-inch pea gravel per cell

SSF-10 Specifications

5 gpm per cell, 7,200 gpd total, 14,400 gpd two cells total.
Minimum 2 cells, additional cells may be manifolded.
0.1 g/ft^2/minute maximum loading rate
cells 96 inches wide x 97 inches high
wet harrowing
removable lids.
External piezometer for measuring headloss

Flow gauge, brass metering valve for setting flow rate
Brass float valves for maintaining tank water levels
control tank 29 inches wide x 49 inches high
sand - 149 ft^3 per cell .35mm effective size $U_c < 3$
underdrain gravel- 25 ft^3 3/8-inch pea gravel per cell

Media Specifications

pea gravel (3/8 x 6)

Sieve Analysis

Seive	mm	cumu	Passing
#3/8	9.52	100	+/- 0
#3	6.7	88	+/- 15
#1/4	6.35	84	+/- 19
#4	4.75	17	+/- 4
#6	3.35	5	+/- 3
#8	2.35	1.3	+/- 1

35 mm silica sand. U_c (uniformity coefficient) = 1.5 to 2

Sieve Analysis

Seive	mm	cumu	Passing
#16	1.180		
#20	0.850	100	+/- 0
#30	0.600	92	+/- 1
#40	0.425	34	+/- 2
#50	0.300	7	+/- 1
#70	0.212	1	+/- 0
#100	0.150		

Parts not included

12î square (approximate) concrete tiles for splash plates

APPENDIX E

Disinfection Procedures

In this appendix, the disinfection procedures are divided into three parts. The first part covers well disinfection procedures, the second covers disinfection of storage tanks and water treatment equipment, and the third covers the water distribution system.

Part 1 Well Disinfection Procedures

1. Remove all pump parts from the well.
2. Compute the entire volume of water in the well including the amount in the gravel pack.
3. Add the amount of HTH necessary to have a concentration of 100 ppm for the entire volume of water in the well.
4. Leave chlorine in the well at least 48 hours occasionally mixing of the solution with the pump. This can be accomplished by disconnecting the drop pipe or hose from the pump, suspending it in the well, and letting the pump run in the well for a few minutes.
5. Spray the portion of the inside surface of the well above the water line with a 100 ppm chlorine solution several times during the 48-hour time period.
6. After 48 hours, disinfect the pump parts, cables, drop pipe or hose, etc, immediately before replacing in the well. This can be done by placing all parts on a skid and brushing the exteriors with a 100 ppm chlorine solution. The chlorine solution should also be poured through any pipes to be place inside the well.
7. Pump the well until the chlorine residual is between 1 ppm and 2 ppm.
8. Test for bacteria after all pump parts are back in the well.

Bill of Materials for Well Disinfection

Swimming pool chlorine tester color indicator
Sufficient sized generator
½ HP pump with control box, 230 volts, single phase
1 HP pump with control box, 230 volts, single phase
300 ft pump cable
Splice kits for cable
300 ft of ¾-inch high pressure garden hose
300 ft of ½-inch poly rope
Connectors or fitting to adapt pump discharge fitting to hose
¾-inch valve with connectors to hook up to garden hose
Sprayer for end of garden hose
HTH
1000 – 8-inch plastic ties

References: Driscoll, Groundwater and Wells, Second edition; Baehr, Operation Guidelines for HCA Water Well Drilling; NAVFAC P-1065, Multiservice Procedures for Well Drilling Operations

Part 2 Storage Tanks and Water Treatment Tanks

The water storage facility and all treatment tanks shall be filled to the overflow level with potable water to which enough chlorine has been added to provide a free chlorine residual of 10 ppm (10 mg/L) at the end of 24 hours. After the retention period the free chlorine residual in the storage and treatment tanks shall be reduced to a concentration of not more than 2 mg/L. This can be accomplished by completely draining the tank or a combination of draining the tank and introducing well water. The environment to which the highly chlorinated water is to be discharged shall be inspected. If there is any question that the chlorinated discharge will cause damage to the environment, then a reducing agent shall be applied to the water to be wasted to neutralize thoroughly the chlorine residual remaining in the water. After the chlorination procedure is complete and before the storage tanks and water treatment tanks are placed in service, water from the full tanks shall be sampled and tested for coliform organisms. The testing shall be either the multiple tube fermentation technique or the membrane filter technique. Such water should also be tested to assure that no offensive odor exist due to chlorine reactions or excess chlorine residual. If the sample shows the presence of coliform bacteria, then repeat samples shall be taken until two consecutive samples are negative, or the tanks shall again be subjected to disinfection.

Part 3 Water Distribution

Each unit of completed waterline shall be disinfected. After pressure tests have been made, the unit to be disinfected shall be thoroughly flushed with water until all entrained dirt and mud have been removed before introducing the chlorinating material. The chlorinating material shall be either liquid chlorine, conforming to AWWA B301 or calcium or sodium hypochlorite. The chlorinating material shall provide a dosage of not less than 50 ppm and shall be introduced into the water lines. PVC pipe lines shall be chlorinated using only the above specified chlorinating material in solution. The agent shall not be introduced into the line in a dry solid state. The treated water shall be retained in the pipe long enough to destroy all non-spore forming bacteria. The retention time shall be at least 24 hours and shall produce not less than 25 ppm of free chlorine residual throughout the line at the end of the retention period. Valves on the lines being disinfected shall be opened and closed several times during the contact period. The line shall then be flushed with clean water until the residual chlorine is reduced to less than 1.0 ppm. From several points in the unit, USSOUTHCOM personnel shall take at least three (3) water samples in proper sterilized containers and perform a bacterial examination in accordance with the local water authority's or USACHPPM's approved methods. The local water authority or a local laboratory approved or recommended by the local water authority shall perform laboratory testing. The disinfection shall be repeated until tests indicate the absence of pollution for at least two (2) full days. The system will not be turned over to the local community or water authority until satisfactory bacteriological results have been obtained.

COMMON CHLORINE SOLUTIONS FOR USE IN WELL DRILLING
(for 1000 gallons of water)

REQUIRED CONCENTRATION (mg/L)	Sodium Hypochlorite (LIQUID BLEACH) 5% CONCENTRATION (gallon)	Calcium Hypochlorite (HTH) 65% HYPOCHLORITE (pounds or cups)
50	1	0.64 or 1-1/8
100	2	1.28 or 2-1/4
500	10	6.40 or 5-5/8
1000	20	12.80 or 11-1/4

If more accurate numbers are required or different volumes of sterilant concentrations are used, the following equations apply:

Calcium Hypochlorite (HTH):

$$\text{Weight (lbs)} = \text{Water Volume (gal)} \times 8.33 \times \left[\frac{\text{required concentration (mg/L)}}{\text{Sterilant concentration (\%)}}\right]$$

Sodium Hypochlorite (Liquid Bleach):

$$\text{Volume (gal)} = \frac{\text{Water volume (gal) } 8.33 \left[\dfrac{\text{required concentration (mg/L)}}{\text{Sterilant concentration (\%)}}\right]}{8.33}$$

Notes:

1. When using the above equations, both required and sterilant concentrations should be decimal form. For example: mg/L of 1000 = 0.001; percent available chlorine of 5% = 0.05.
2. mg/L conversion from trade percentages may be determined by using the following equation:

   mg/L = trade percent x 10,000

3. The conversion of pounds to cups of calcium hypochlorite is based on the weight of 1 gallon of calcium hypochlorite (where 1 gallon is equal to 9 pounds) divided by 16 cups (where 1 cup is equal to 0.5625 pounds).

Material Specifications for Hypochlorites

Description of Hypochlorites from AWWA B300.

- Chlorinated lime (bleaching powder, chlorine of lime) is a fine, yellowish-white, hygroscopic powder of about 38 to 53 (pounds per cubic foot) lb/ft^3 bulk density, containing from 25% to 37% available chlorine by weight. It is manufactured by the action of chlorine on selected slaked lime. The material contains some free lime. The exact formula is a matter of controversy. One generally accepted formula is $CaO \cdot 2CaOCl_2 \cdot 3H_2O$.

- Calcium hypochlorite [$Ca(OCl_2)$] is white or yellowish-white granular powder, granule or tablet containing 65% to 70% available chlorine by weight. The bulk density of the granular powder is about 32 to 50 lb/ft^3, and of the granules about 68 to 80 lb/ft^3. It may be manufactured by adding chlorine to a milk of lime slurry, which may be prepared by mixing hydrated lime with water or slaking quicklime with water.
- Sodium hypochlorite solution (NaOCl) is a clear light yellow liquid containing up to 160 g/L available chlorine (16 trade percent). One method of manufacture is by passing chlorine into a caustic soda solution or into a caustic soda-soda ash mix.
- Available chlorine is a term used to express the oxidizing power of the chlorine contained in the compounds described in the AWWA B300 standard. It can best be expressed in one of three ways. The basic formulas are:

1. **Volume or Trade Percent =** $\dfrac{\textbf{Grams available chlorine per liter}}{\textbf{10}}$

2. **Percent Available Chlorine by Weight =**

$$\frac{\textbf{Trade Percent}}{\textbf{Specific gravity of solution}}$$

3. **Percent Available Chlorine by Weight =**

$$\frac{\textbf{Grams per liter}}{\textbf{10 X specific gravity of solution}}$$

Impurities

The hypochlorites supplied under the specifications of the AWWA B300 standard shall contain no soluble mineral or organic substances in quantities that would be harmful to anyone consuming water treated with acceptable quantities of hypochlorite. Furthermore, this standard shall not cause any abnormal difficulty in the operation of chemical feeders designed for feeding hypochlorite solutions.

Physical Requirements

- Chlorinated lime shall be substantially free from lumps. It shall not contain any dirt or foreign material.
- Calcium hypochlorite granular powder or granules shall be substantially free of lumps. Not more than 10% of the powder shall pass a 100-mesh screen. It shall not contain any dirt or other foreign material.
- Calcium hypochlorite tablets shall be uniform in shape. The weight of the tablets shall not vary by more than 5% from the average value stated on the label. Not more than 2% of the tablets shall be broken.
- Sodium hypochlorite solution shall be a clear liquid containing not more than 0.15% insoluble material by weight.

Chemical Requirements

- Chlorinated lime shall contain not less than 25% available chlorine by weight.
- Calcium hypochlorite shall contain not less than 65% available chlorine by weight when shipped.
- Sodium hypochlorite shall contain not less than 100 g/L available chlorine (10 trade %).
- The total free alkali (as NaOH) in sodium hypochlorite shall not exceed 1.5% by weight.

APPENDIX F
Hand Pumps

APPENDIX F.1

Dempster Hand Pumps

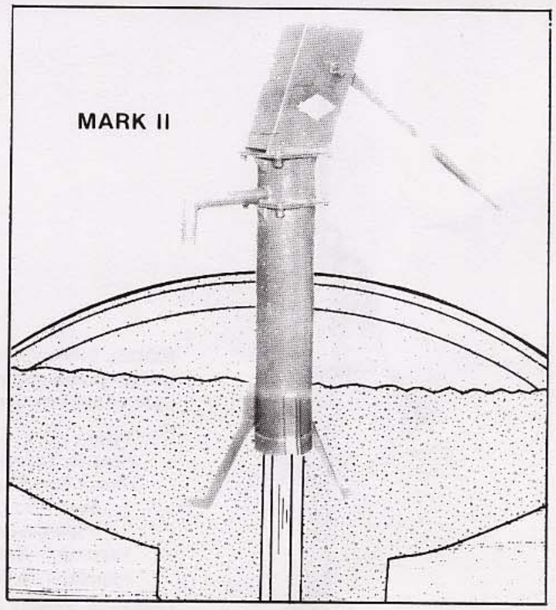
SINCE 1878 DEMPSTER INDUSTRIES INC.®

DATA SHEET 380-6 Issue Date 7/88

HAND PUMPS

EXTREME DUTY CONTINUOUS TO NORMAL DUTY FAMILY -

Full Range of Hand Pump Usage



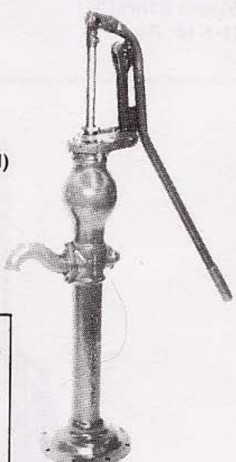
#1 EXTREME HEAVY DUTY CAPABILITY

The Mark II is manufactured to strict industry standards for complete interchangeability of repair parts. It was designed through the joint efforts of a number of world service organizations. This pump's purpose is for long life under extremely adverse conditions, such as village wells, to 262 feet (80 meters) deep. It is intended to operate 20 millions of cycles before any repair is required. Recommended installation is for the pump base and casing pipe to be imbedded in a cement platform and foundation to seal the well. This provides an easily cleaned surface with a sloping drain into a soak pit for a *PROTECTED* source of potable water.

#2 MEDIUM DUTY CAPABILITY FOR FAMILY WELLS

This current Model 23F hand pump is an updated modification of the older pump below, used for many years as a single family well pump here in the United States. It is simple and has a good working life under most circumstances. Hardened 5/8" steel pins, oversize bearings and chrome-plated connecting rod increase its life by 2 or 3 times. Sealed top with brass packing nut. Available for 2" or 1-1/4" U.S. NPT or British BSPT pipe thread. Average adult can pump from up to 165 feet (50 meters) with a 2" (5.08 cm) well cylinder.

MODEL 23F (1-1/16" Rod)



Stroke	5 Inch
Well Rod	7/16"
Rear Tapping	1-1/4"NPT

#3 NORMAL DUTY FOR INDIVIDUAL FAMILY WELLS

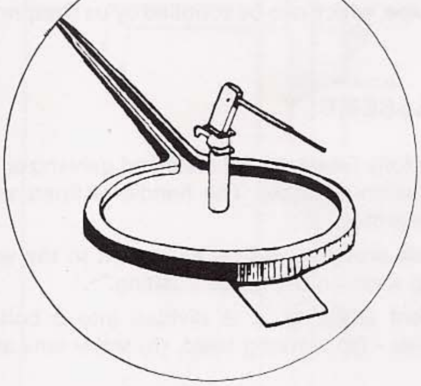
The Model 40F (original Model 23F) hand pump has been used many years for individual family wells. Therefore, there are thousands in use around the world. It is extremely simple to repair with standard tools and hardware. Sealed top. Same sizes as 23F above.

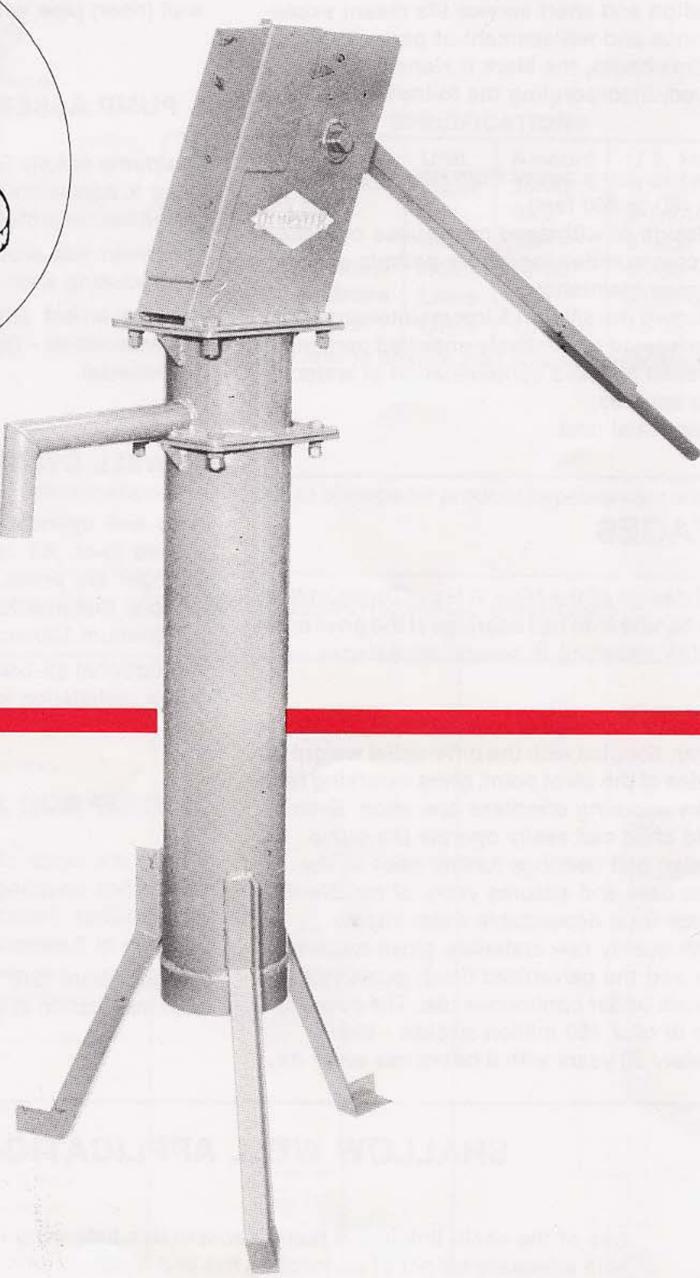
MODEL 40F (11/16" Rod)

DEMPSTER INDUSTRIES INC. Beatrice, NE 68310 Phone (402)223-4026 Toll-Free 1-800-777-0212

MARK II HAND PUMP

SINCE 1878
DEMPSTER
INDUSTRIES INC.





MARK II HAND PUMP

INTRODUCTION

A hand pump in a cased well is the most practical and economical means of providing a safe, potable water supply in rural or underdeveloped areas. Conventional hand pumps used for the past several decades were primarily designed for intermittent use in shallow wells, or in many cases, with a windmill. In continuous use, the low discharge rates, inefficient manual operation and short service life meant excessive maintenance and replacement of parts. To overcome these drawbacks, the Mark II Hand Pump has been developed, incorporating the following features:

- Engineered to pump easily from depths of 18 to 80 meters (60 to 260 feet).
- Rugged design to withstand continuous operation by larger communities for longer periods of time with minimum maintenance.
- Uncomplicated installation & low maintenance cost. Can be performed by relatively unskilled personnel.
- Fully enclosed to avoid contamination of water by outside sources.
- Reasonable initial cost.

ADVANTAGES

The practical design of the Mark II Hand Pump utilizes a long, heavy handle with ball bearings at the pivot point and a chain link, resulting in several advantages.

- A mechanical advantage of approximately 8:1 in the handle lever, coupled with the differential weight on the two sides of the pivot point, gives a working ratio of over 30:1 ensuring effortless operation. Even a 10 year-old child can easily operate the pump.
- Use of sealed ball bearings further adds to the operational ease and ensures years of trouble-free performance for a dependable water supply.
- Use of high quality raw materials, close machining tolerances and the galvanized finish guarantees long life, even under continuous use. The pump has a life span of over 150 million strokes - this is approximately 20 years with 8 hours use every day.

DESCRIPTION

The Mark II Hand Pump consists of 3 major components:

1. Pump Head Assembly
2. Well Cylinder
3. Pump Rod Assemblies

These three components are completely galvanized and form a pump unit ready for installation, except for the well (riser) pipe, which can be supplied by us if required.

1. PUMP ASSEMBLY

The pump is fully fabricated of steel and galvanized to make it corrosion-resistant. The handle is fitted with sealed ball bearings.

The chain link provides vertical alignment to the well rod, reducing wear on the guide bushing.

For convenient shipping, it is divided into 3 bolted sub-assemblies - (a) working head, (b) water tank and (c) pedestal.

2. WELL CYLINDER ASSEMBLY

The well cylinder has a cast iron body with a brass sleeve liner. All components of the check valve and plunger are brass. The cup leathers are made from a special material for maximum service life. For use in a minimum 100mm I.D. (4") well casing.

An optional all-brass well cylinder with flush end caps allow installation in smaller wells of 80mm (3") I.D.

3. PUMP ROD ASSEMBLIES

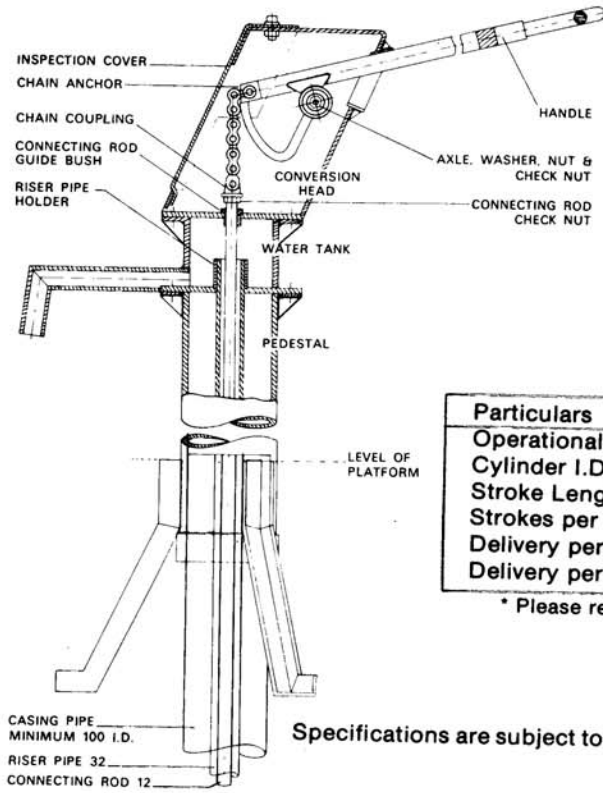
These are made of 12mm (1/2") galvanized mild steel with a hex coupling threaded to one end and a lock nut at the other. These are normally supplied in standard lengths of 3 meters (10 feet).

Larger 16mm (5/8") rods are also available for shallow well installation at depths of 18 to 25 meters (60-80 feet).

SHALLOW WELL APPLICATIONS

Use of the chain link in the pump necessitates balancing the handle weight with adequate weight of connecting rod and water column. When cylinder is installed from 18 to 25 meters (60 to 80 feet), 16mm (5/8") diameter well rod must be used for all except the top rod which connects to chain link.

MARK II HAND PUMP



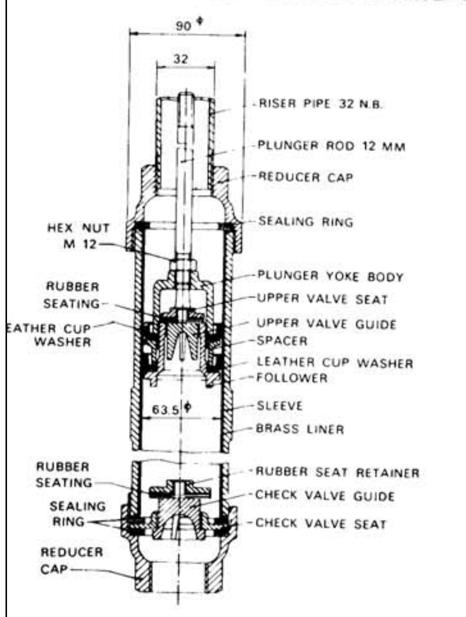
SPECIFICATIONS

Particulars	Unit	Amount	U.S. Measure
Operational Depth	Meter	25-80*	80-260 Feet
Cylinder I.D.	mm	63.5	2-1/2 Inch
Stroke Length	mm	100	6 Inch
Strokes per Minute	Nos.	40-50	40-50
Delivery per stroke	Liters	0.32	0.085 Gallons
Delivery per hour	Liters	To 1000	To 265 Gallons

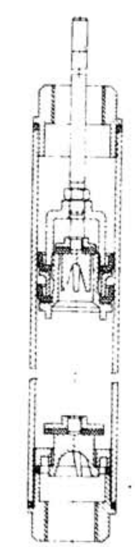
* Please refer to Shallow Well note for lesser depths.

Specifications are subject to change for product improvement without notice.

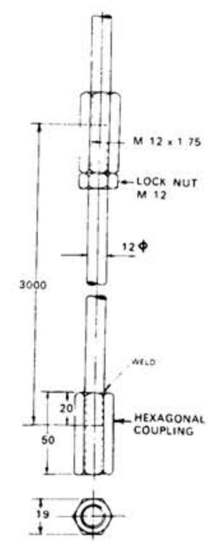
NOTE : ALL DIMENSIONS ARE IN MM UNLESS OTHERWISE MENTIONED



#1133 CAST IRON BRASS LINED WELL CYLINDER



#442 FLUSH CAP BRASS WELL CYLINDER



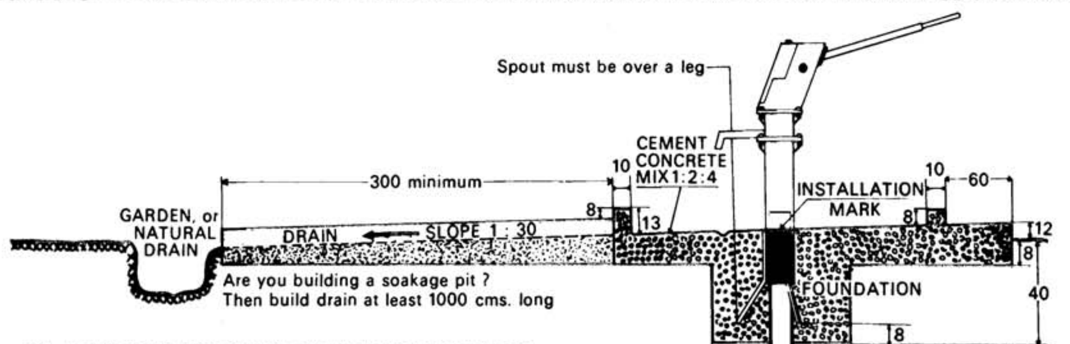
CONNECTING ROD ASSEMBLY

MARK II HAND PUMP

INSTALLATION & MAINTENANCE

The Mark II Hand Pump is extremely simple. The installation & maintenance can be performed at the local level with little training required. A manual is included with each pump, which gives step-by-step illustrations of both procedures. Extra manuals are available upon request.

The cast iron well cylinder can be installed in a 100mm (4 inch) well casing and the flush cap models can be installed in 80mm (3 inch) casings.



PLATFORM FOR MARK II HANDPUMPS

DIMENSIONS IN CENTIMETRES

EXPORT PACKING

Items are packed in seaworthy wooden crates, consistent with customer requirements and preference. Each packing crate is lined with waterproof paper and suitable secured with banding material. Consult the factory for special packing, crating or other requirements.

DEMPSTER INDUSTRIES INC.

711 South 6th Street
P.O. Box 848
Beatrice, Nebraska
68310

WATS LINE: 1-800-777-0212

Producers of Windmills, Hand Pumps, Well Cylinders, Submersibles, Jets, Centrifugals, Solar Pumps, Pump Jacks and Fertilizer Application Equipment.

DATA SHEET 380-5 Issue Date 7/86

DEMPSTER INDUSTRIES INC

Dempster Industries has been producing water-pumping equipment at Beatrice, Nebraska USA since 1878. The Dempster windmill, well cylinders and other necessary well supplies contributed substantially to the settlement of the North American plains by pioneer farmers and livestock ranchers of the nineteenth century.

Dempster continues to produce the windmill in 6 to 14 ft wheel sizes and towers from 22 to 39 ft tall. They also manufacture 4-inch submersible pumps, jet pumps, electric and gasoline engine powered centrifugal pumps, plus a line of fertilizer application equipment.

ABOUT THIS MANUAL

Who is this manual for?

This manual is for all engineers and mobile maintenance team members who work in rural water supply programs.

What is in this manual?

This manual tells you how to install and maintain the Dempster Mark II Handpump. The Mark II Handpump is different than other handpumps. So you have to install it in a slightly different way. Keep this manual with you when you install or repair a handpump. Then you can refer to it often. It will make you work easier.

Follow all the instructions. Follow them exactly. Remember to use the checklist at the end of the manual.

ABOUT YOU AND HANDPUMPS

Why was the Mark II Handpump developed?

Handpumps in villages are used by many people. Sometimes they are used for 18 hours a day, or even more. Because of this, many handpumps breakdown quickly.

The Mark II Handpump is made of very strong material. It is the best handpump made so far. It seldom breaks down. All the parts are checked and tested so that they fit together perfectly. This means that you do not have to force the parts together.

Why is water from a handpump better than water from the source?

The Mark II Handpump is one of the safest sources of clean, potable water. Water from streams, open wells, and tanks usually carry disease. But the tubewell is sealed so that harmful germs cannot enter it; it is a *protected* source of water.

If people want to stay healthy, they must always have clean drinking water. If they drink even a sip of water, which is not clean, they can get ill. The handpump brings clean drinking water to the villagers. So it is important that the handpump does not fail. It must work well and work for a long time.

Why is your job so Important?

The handpump should always bring good, potable water to the villagers. If you install the handpump correctly, then it will work properly and need very little maintenance. So if your workmanship is good, then you are helping the villagers to stay healthy.

Do you drink only clean water? Do you set an example to the villagers?

For your own benefit, you should only drink water from the Mark II Handpump well, or water that you know is safe. When you work, the villagers will offer you water. Ask them where it comes from. If it is from an open well, or a tank, or a stream, don't drink it. Tell the villagers you drink only tubewell water, because it is safer. Advise them to do the same. In this way, you will set an example to the villagers.

The villagers can see that you are healthy. They can see that you drink only protected water. *You do what you say.* Your example will show the villagers that clean water is connected to good health.

In this way, you can teach the villagers some very important things.

You can teach them to value their handpumps more and to look after their handpumps better.

Then the handpumps that you install will work better and last longer, so your work will be easier, and the villagers will be healthier.

Many children will grow up stronger and healthier because you provided them with good, safe drinking water. You can be proud of your work.

ABOUT THE VILLAGERS AND HANDPUMPS

What should you tell the villagers when you install or repair a handpump?

Here are four important things about handpumps. You should help the villagers to understand these things.

- ❑ *Handpump water is better than water from other sources.* Water from ponds, rivers and tanks can contain disease-carrying germs. If we drink this water, we can get ill. But the water from the handpump is protected from disease. So if we drink water from a handpump, we will stay healthy.

- ❑ *People must use handpumps properly.* You should show the villagers how to use the handpump.

- ❑ *People must maintain handpumps properly.*

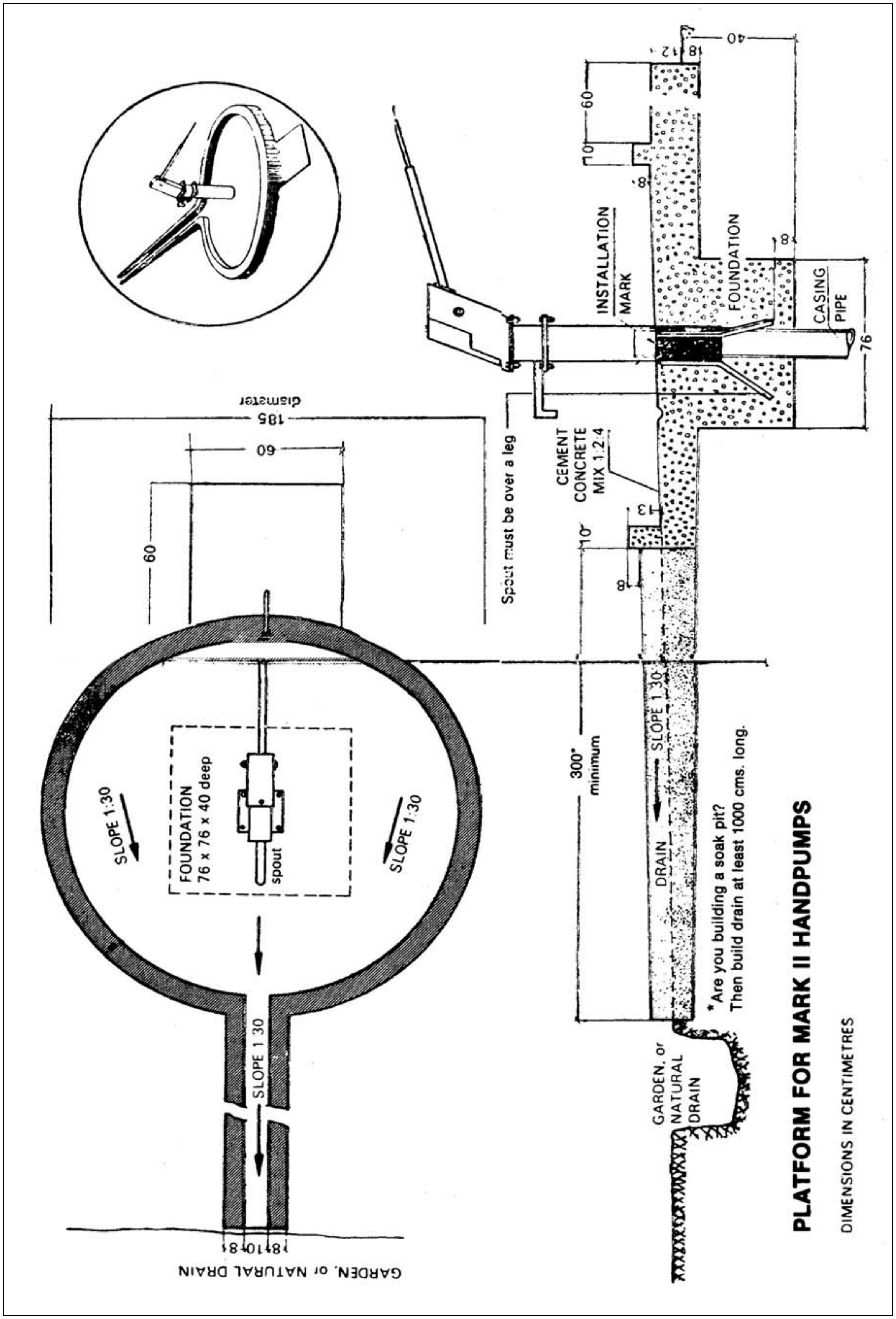
- ❑ *The villagers must contact the appropriate officials if the handpump breaks down.* You should tell the villagers exactly who to contact and how to contact that person.

Here are some "dos" and "don'ts" for using handpumps.

DO	DON'T
Do use the pump gently.	*Do*n't *use the pump roughly.*
Do pump the handle with long, slow strokes.	*Don't* pump the handle with short, quick strokes.

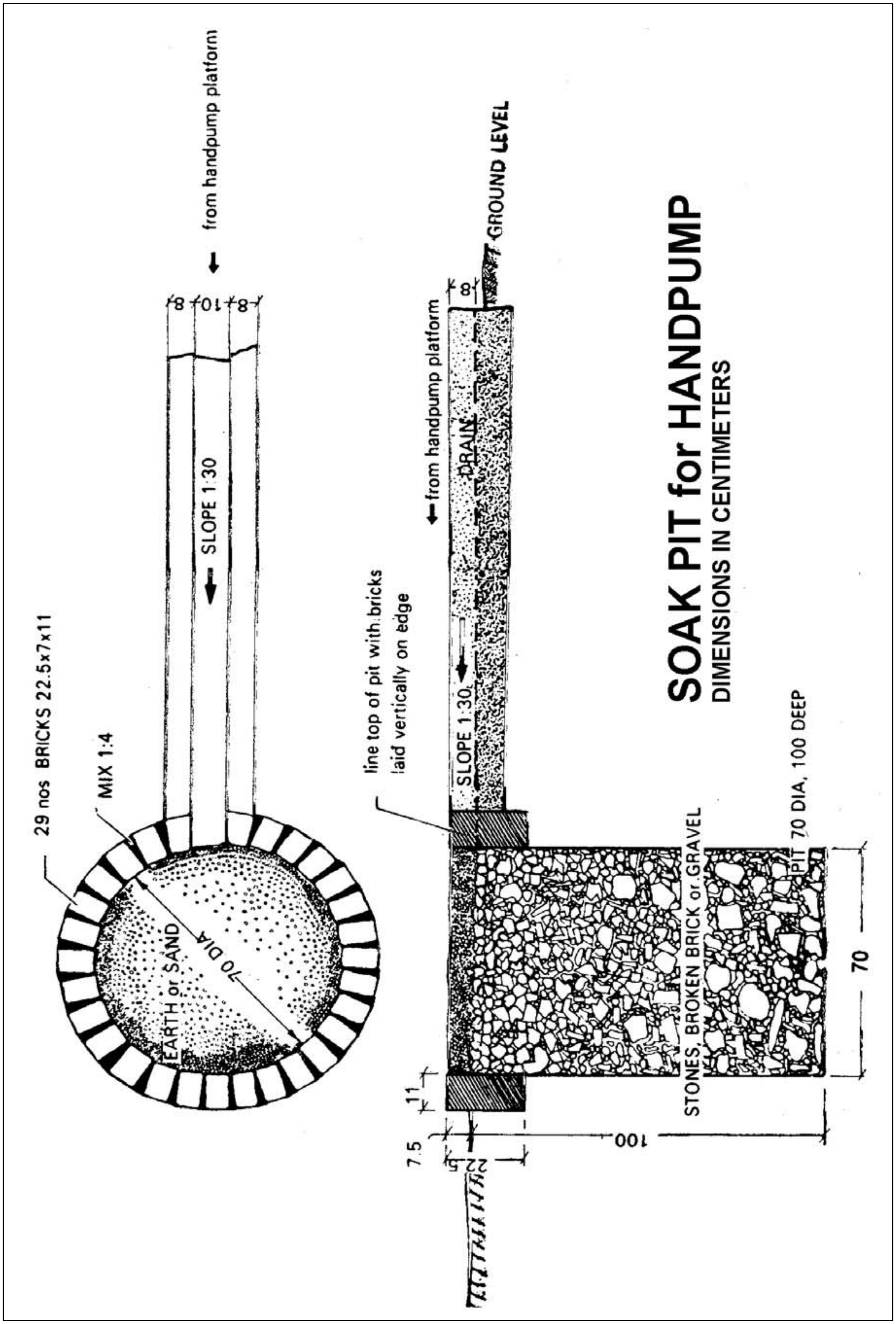
Here are some "dos" and "don'ts" for maintaining handpumps.

DO	DON'T
Do sweep the platform regularly.	*Do*n't *let the platform get dirty.*
Do keep the area around the platform dry.	*Don't* let water collect around the platform.
Do make sure no one throws rubbish near the pump.	*Don't* let rubbish collect near the pump.
Do clean the ground near the pump and keep the drain clean.	*Don't* defecate near the pump.
Do make compost far from the pump	*Don't* let animals defecate near the pump.



PLATFORM FOR MARK II HANDPUMPS

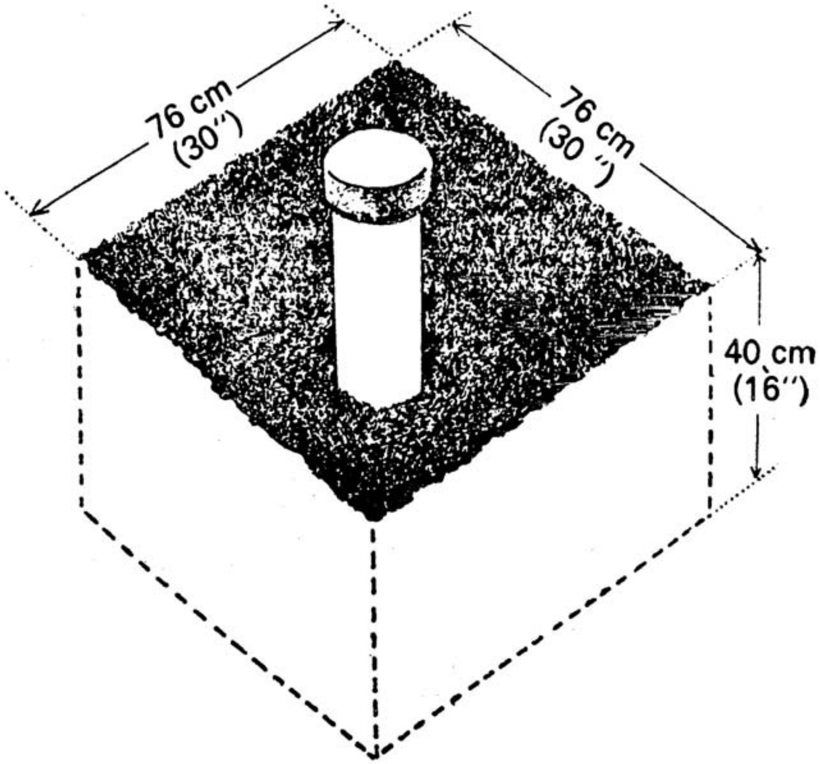
DIMENSIONS IN CENTIMETRES



SOAK PIT for HANDPUMP
DIMENSIONS IN CENTIMETERS
from handpump platform
29 nos BRICKS 22.5x7x11
MIX 1:4
SLOPE 1:30
EARTH or SAND
70 DIA
8
10
8
line top of pit with bricks
laid vertically on edge
from handpump platform
DRAIN
GROUND LEVEL
SLOPE 1:30
STONES, BROKEN BRICK or GRAVEL
PIT 70 DIA, 100 DEEP
70
100
11
7.5
22.5

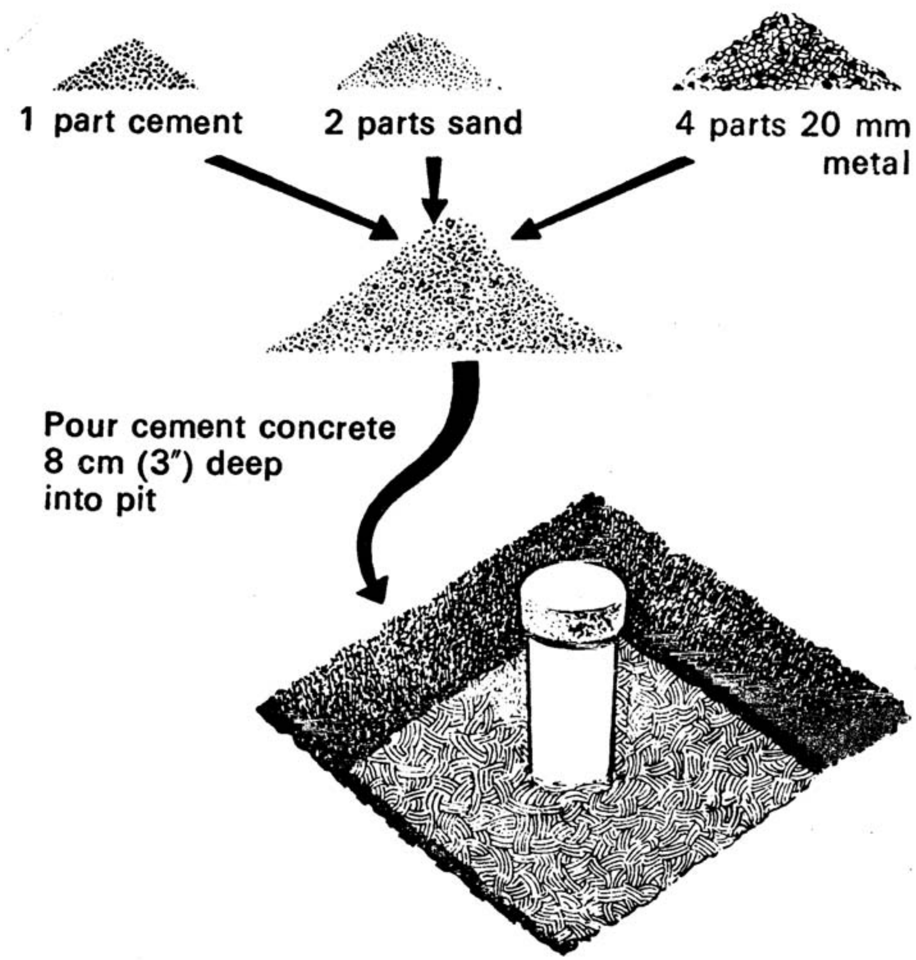
Step 1

1. Cover casing pipe
2. Dig a square pit around casing pipe 40 cm (16″) deep

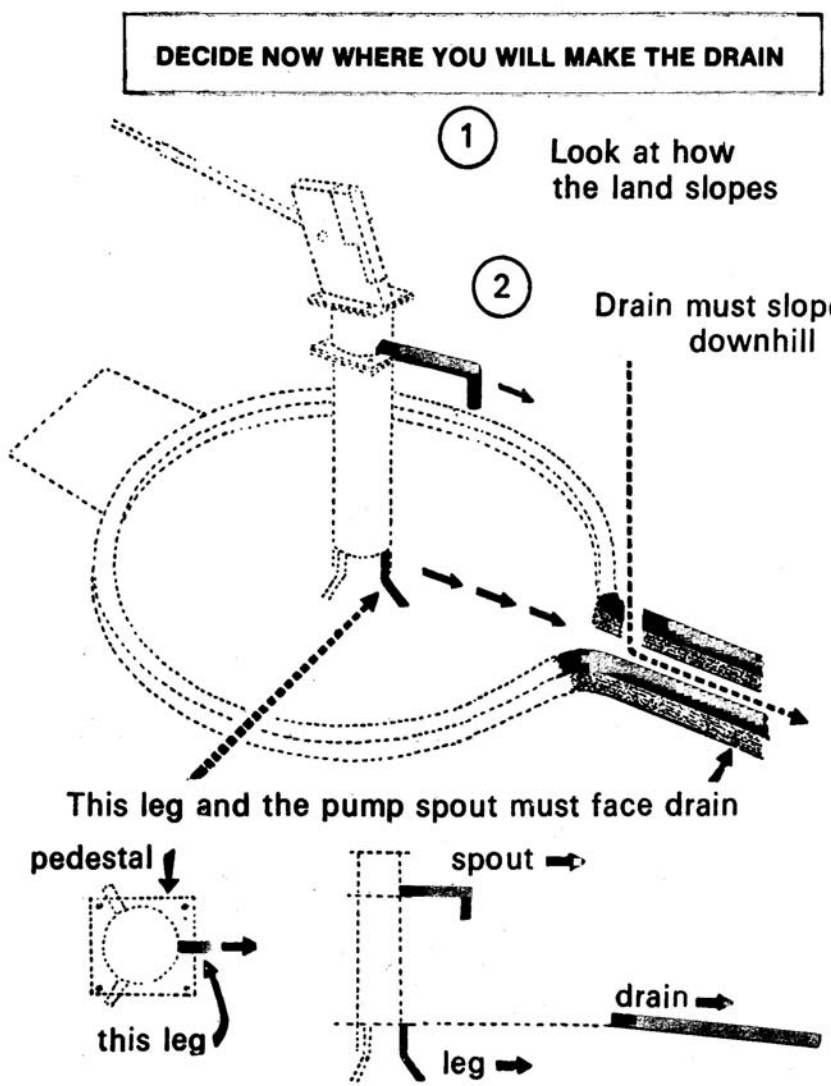


Step 2

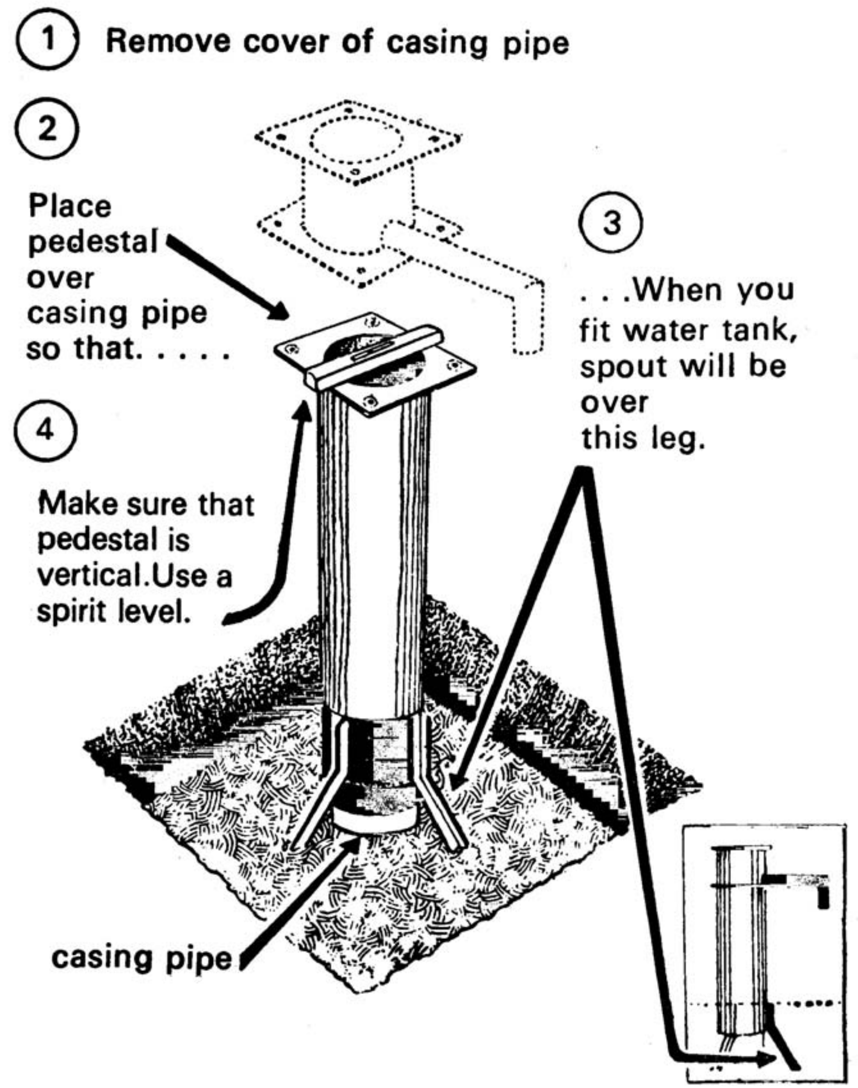
Prepare cement concrete mix



Step 3


DECIDE NOW WHERE YOU WILL MAKE THE DRAIN
1 Look at how the land slopes
2 Drain must slope downhill
This leg and the pump spout must face drain
pedestal
this leg
spout
drain
leg

Step 4

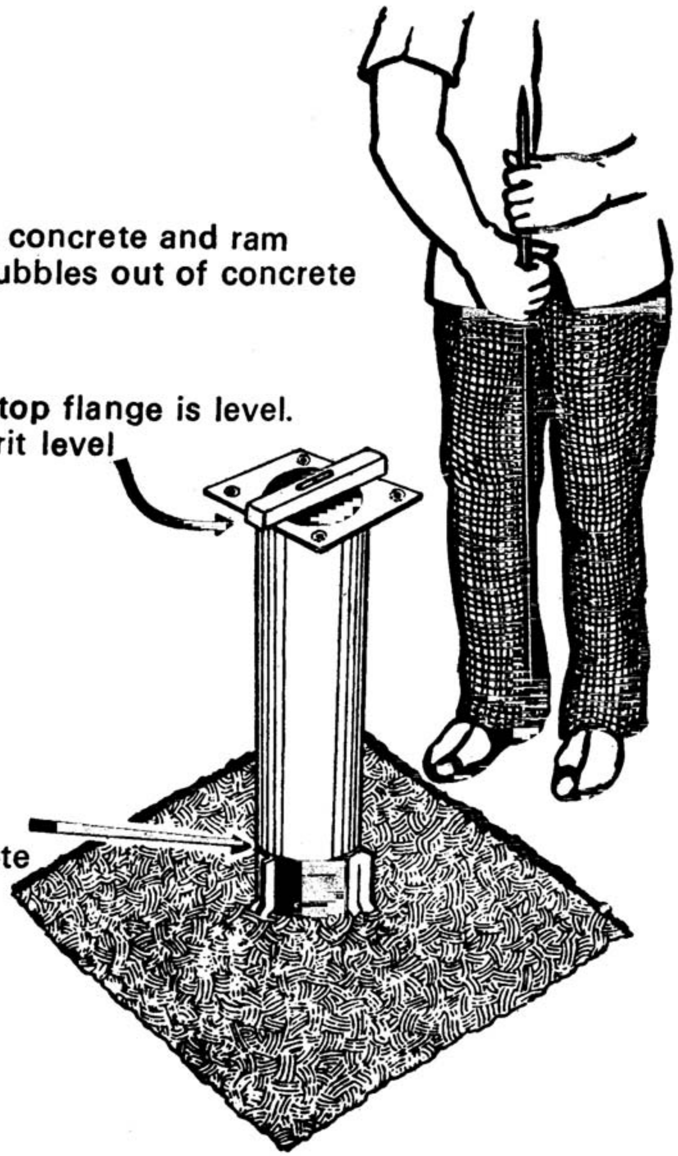

1 Remove cover of casing pipe
2 Place pedestal over casing pipe so that. . . . .
3 . . .When you fit water tank, spout will be over this leg.
4 Make sure that pedestal is vertical.Use a spirit level.
casing pipe

Step 5

① Fill pit with concrete and ram to get air bubbles out of concrete

② Check that top flange is level. Use the spirit level

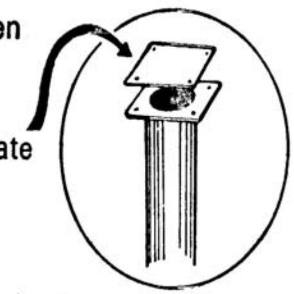
③ Construct platform to top of leg while concrete is still wet



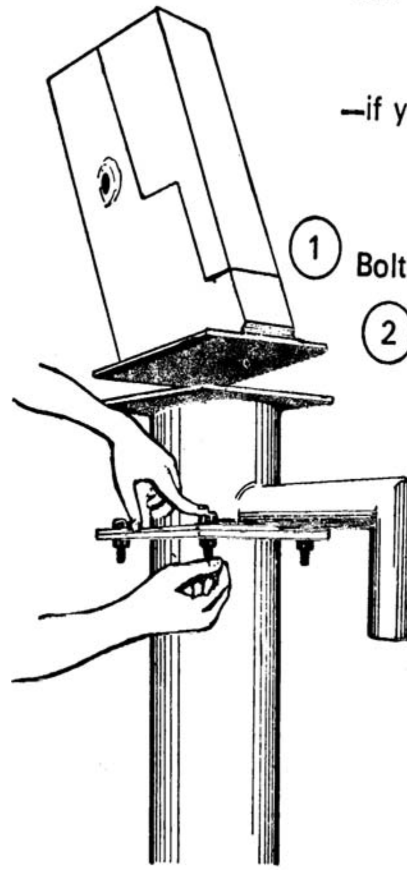
Step 6

Cover pedestal so that children can't put stones in the well

— if you have a cover plate use it



—if you don't have a cover plate. . . .

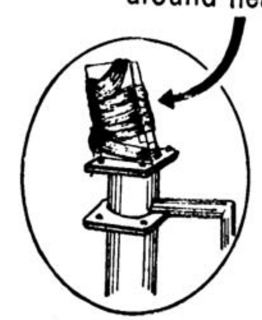


① Bolt on water tank

② Remove handle from head

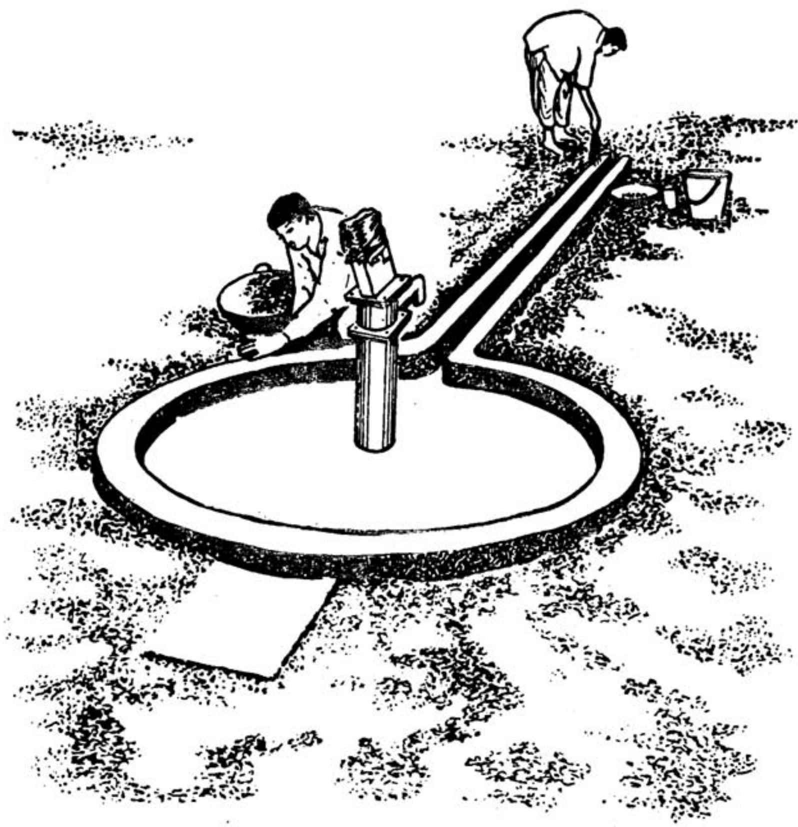
③ Bolt on head

④ Wrap cloth around head



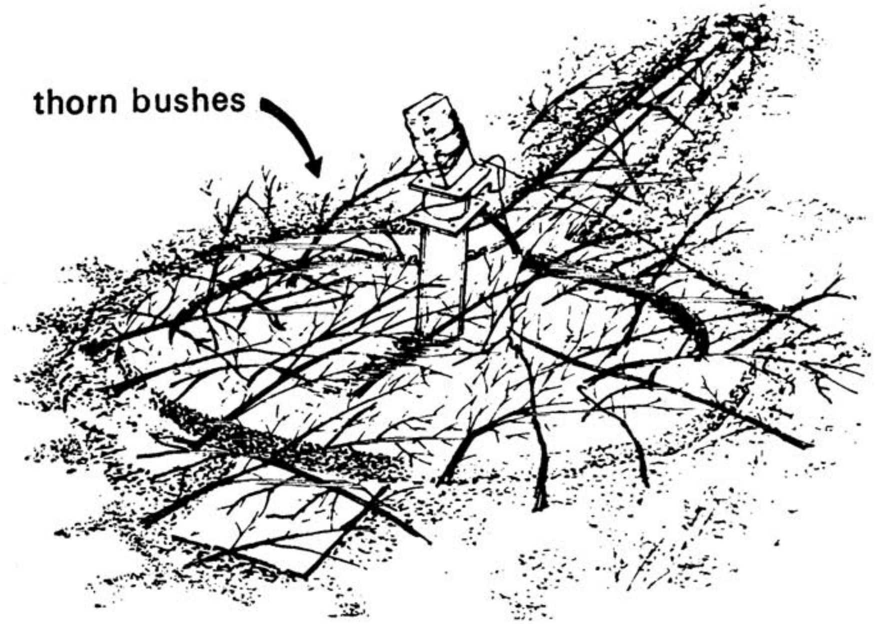
Step 7

Construct platform and drain.
Use plan on pages 8 and 9.



Step 8

To cure concrete, block drain
and fill platform with water.
Ask villagers
to keep away
from installation.

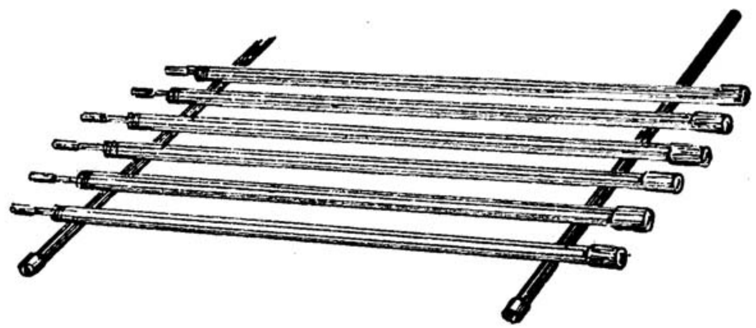


ALLOW CONCRETE TO SET FOR 7 DAYS

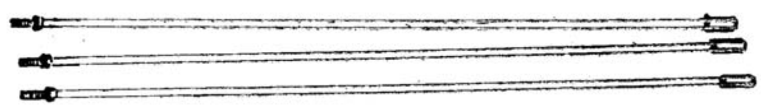
Step 9

SEVEN DAYS LATER

(1) Lay out pipes and connecting rods.
Check that pipes and rods are threaded 40 mm.
Check that all threads are good and clean.



(2) Check rods are fitted with check nuts and couplings

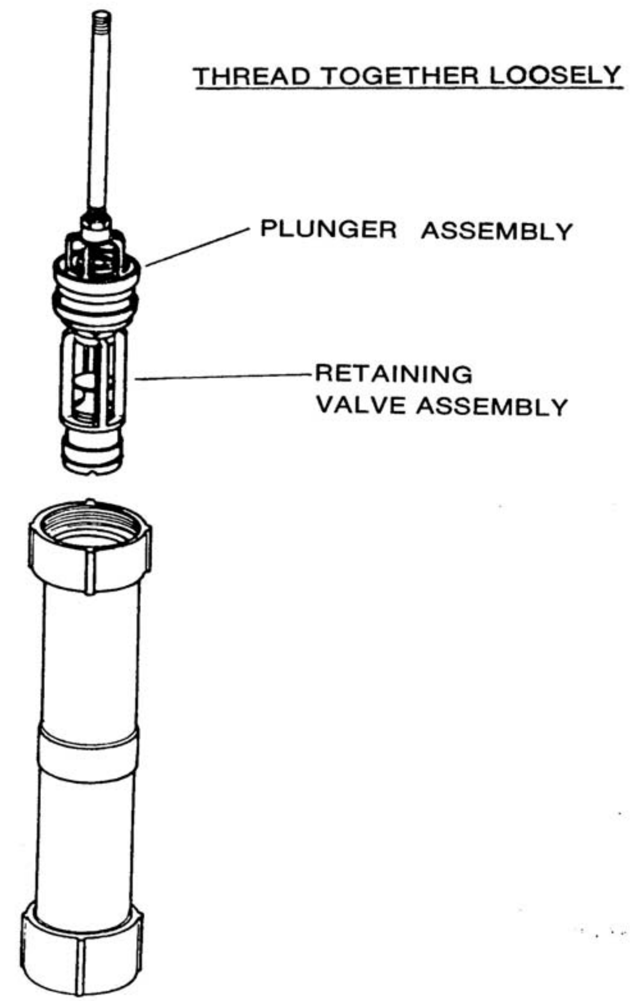


(3) If rods have couplings welded at one end, fit check nuts at the other end

(4) Make sure you have spare check nuts

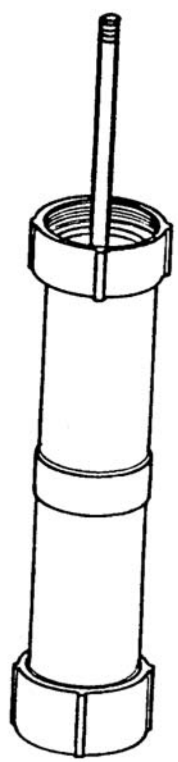
Step 10

Engage plunger assembly.
Connect the plunger assembly with the retaining valve assembly and insert into the body of the cylinder.



Step 11

Free the plunger assembly after hacing seated the retaining valve assembly.

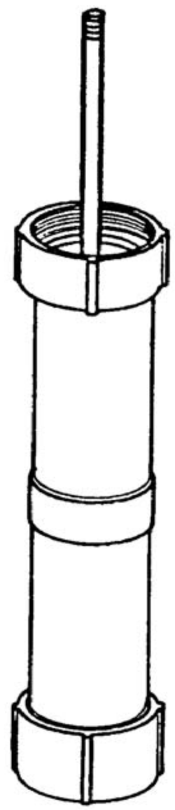


Step 12

Test the cylinder in a bucket of water.

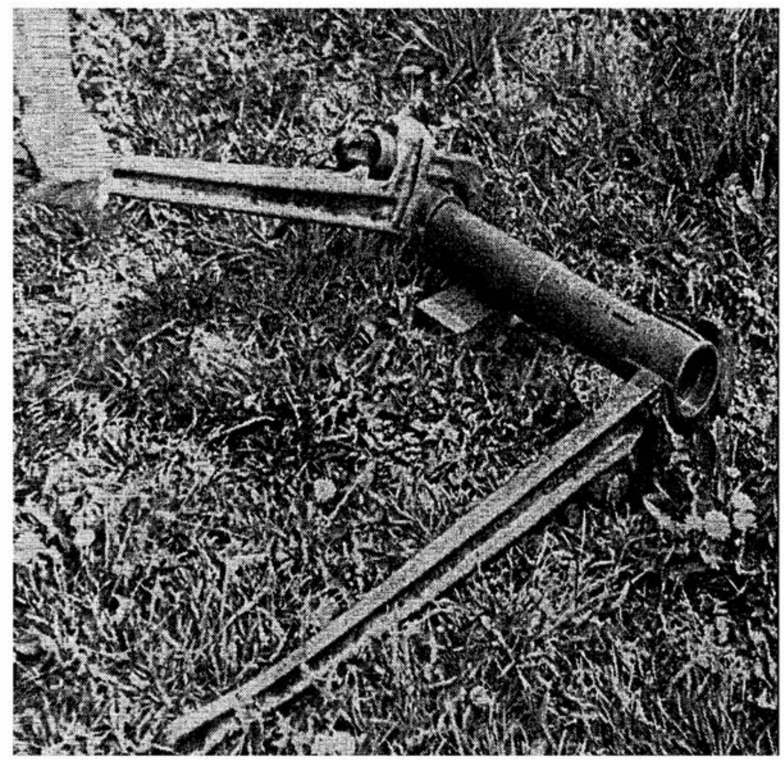
Step 13

Test and be sure the valve does not leak.



Step 14

Remove and check function of valve and plunger. Be sure the cylinder caps are well tightened.

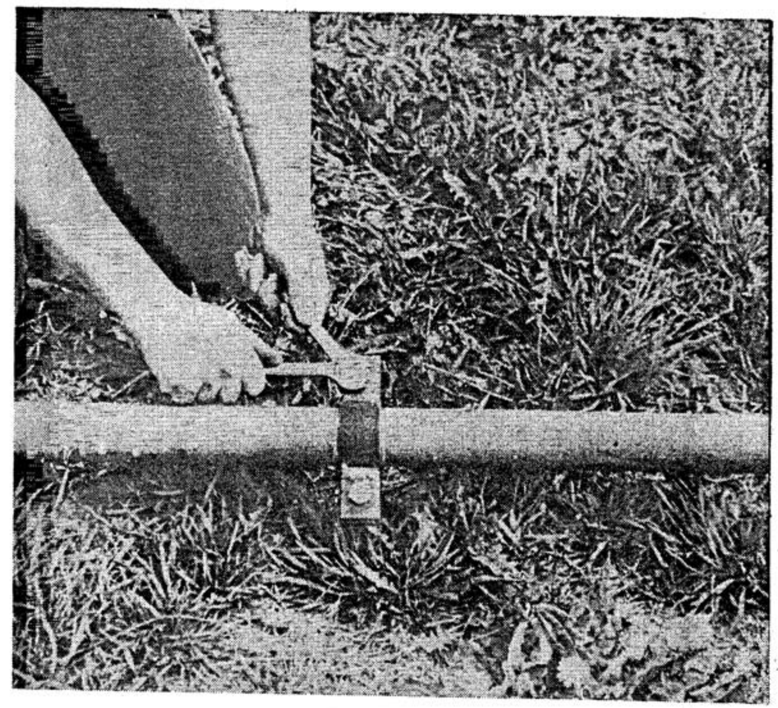


Step 15

Connect the cylinder with the 2½" tube so that the bottom the coupler has free play. Use sealer product on pipe threads.

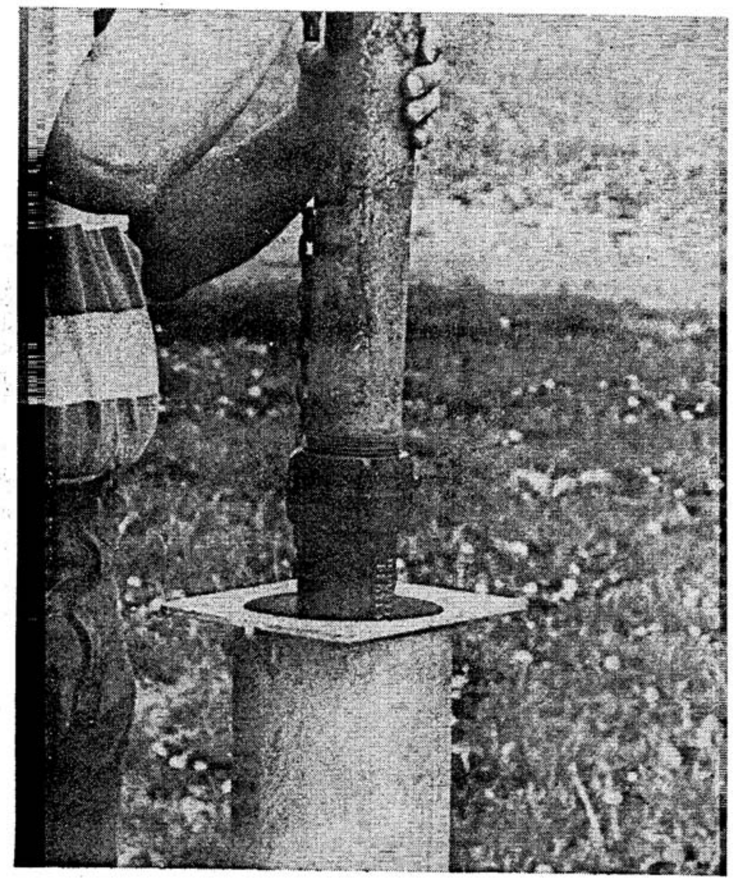
Step 16

Put a pipe sealer product on threads of the pipes. Tighten completely.



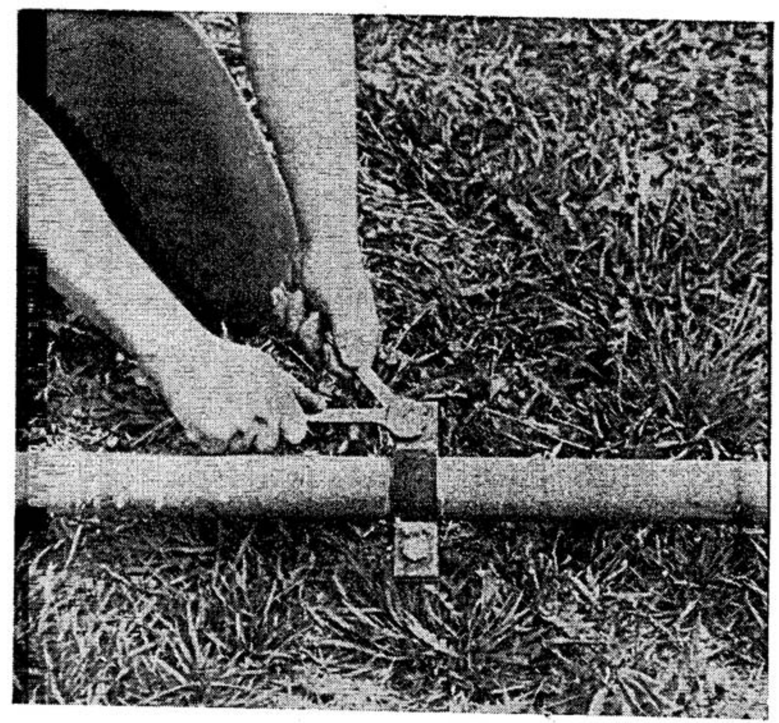
Step 17

Put the first pipe down with the cylinder.



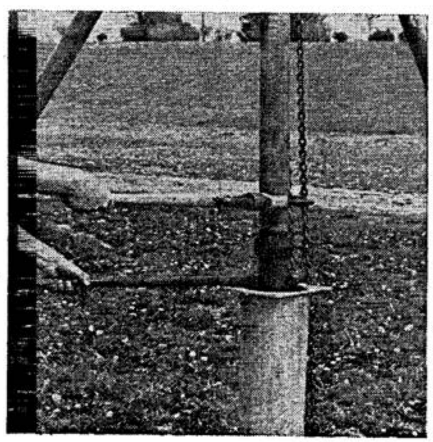
Step 18

Attach the holding collar before putting each succeeding pipe down. Put pipe down with the help of a three-legged base and chain pulley.



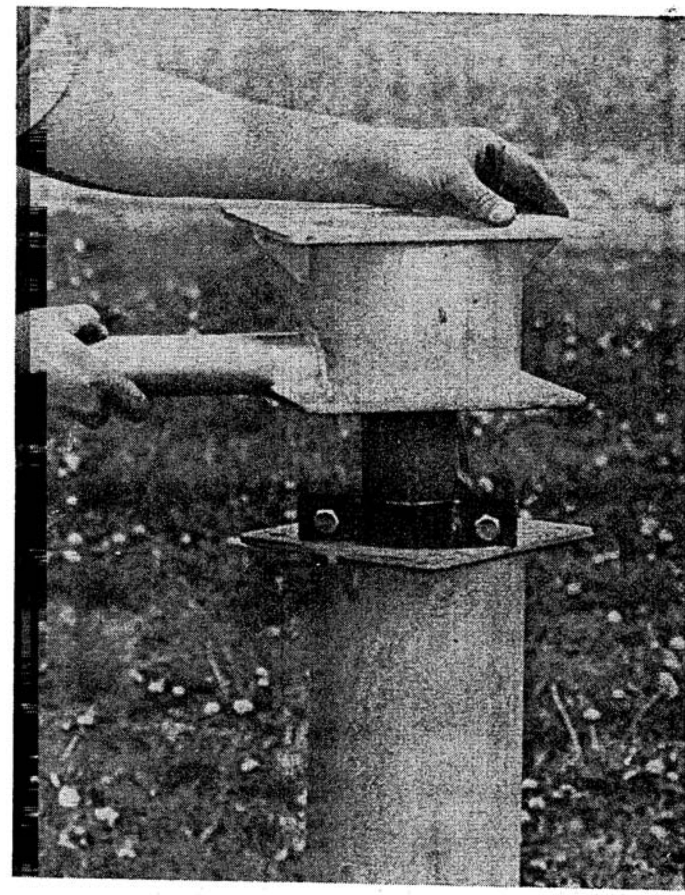
Step 19

Put a pipe sealer product on the threads of the pipe before using a wrench to attach one pipe to another. Tighten completely.



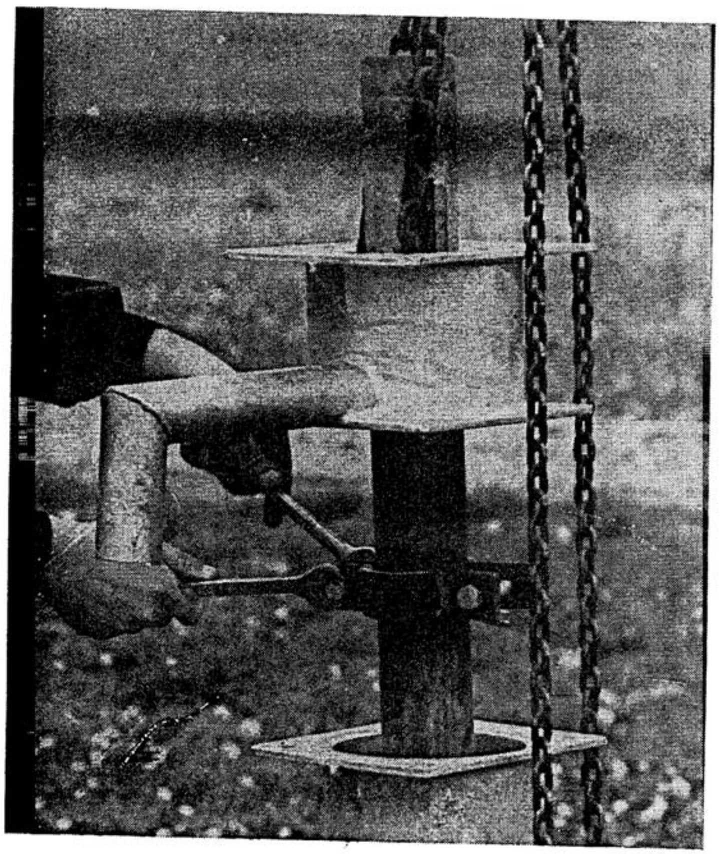
Step 20

Turn the water tank onto the last pipe. Stop rotation of the clamp by insertion of two bolts into the holes on side of support.



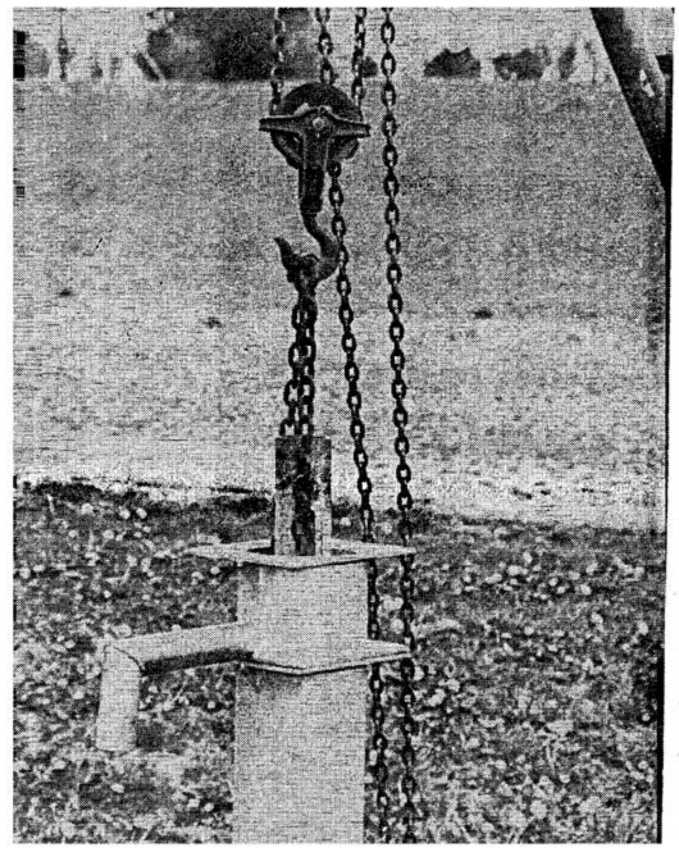
Step 21

Attach the raising tool to the coupling on the water chamber. Raise the water chamber with the help of the chain pulley and remove the holding collars.



Step 22

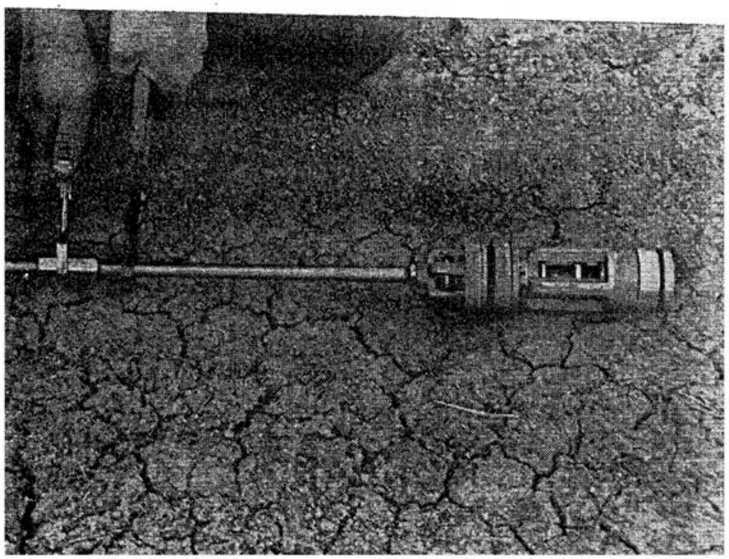
With the help of a chain pulley, lower the water chamber onto the support. Tighten bolts and nuts completey.



Step 23

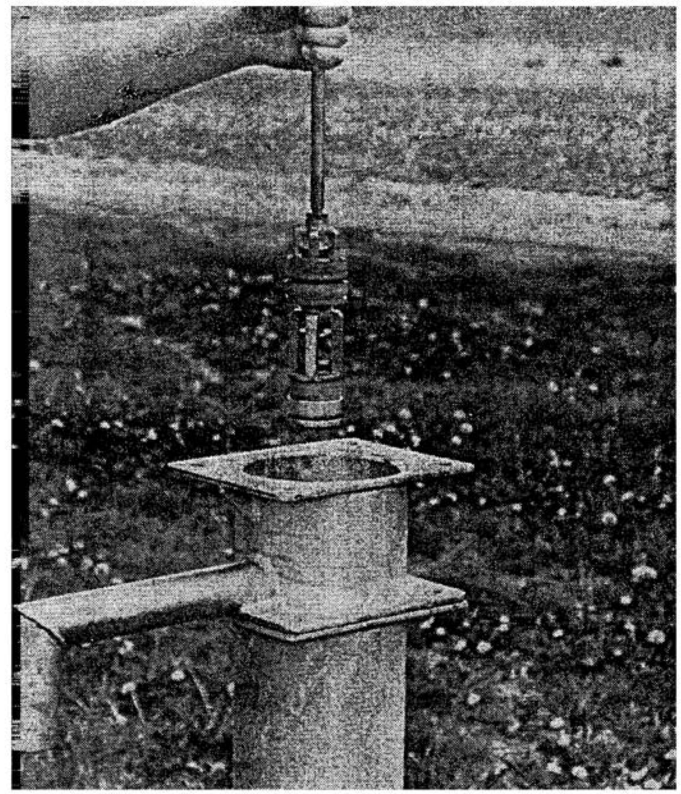
Connect the valve and plunger with the first rod.

Valve and plunger assemblies should be loosely connected. *(DO NOT TIGHTEN COMPLETELY)*



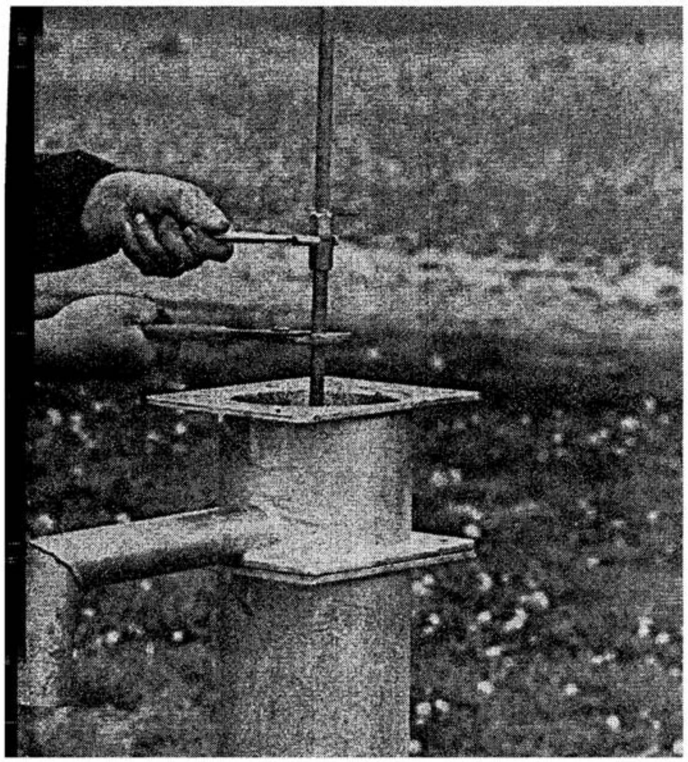
Step 24

Insert the assembly through the water chamber.



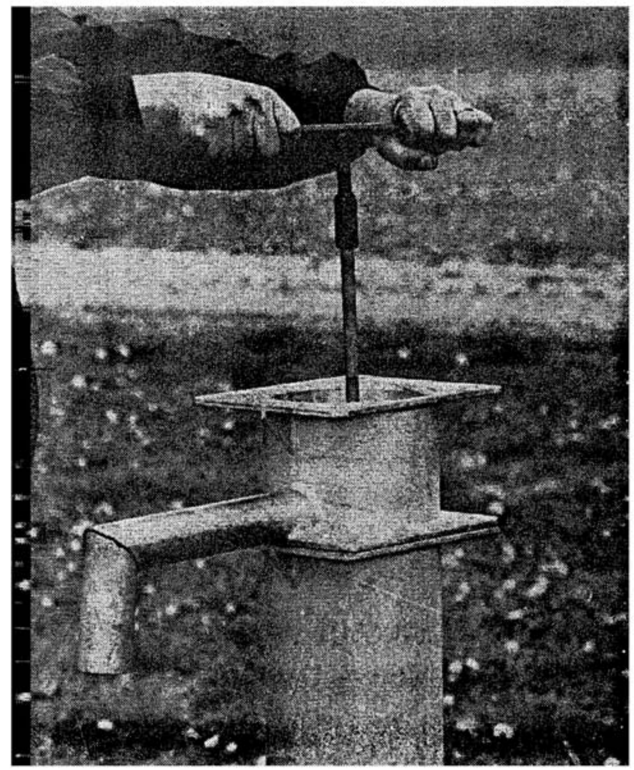
Step 25

Connect each rod with a pliers and open wrench. Drop the rod by hand to next coupling.

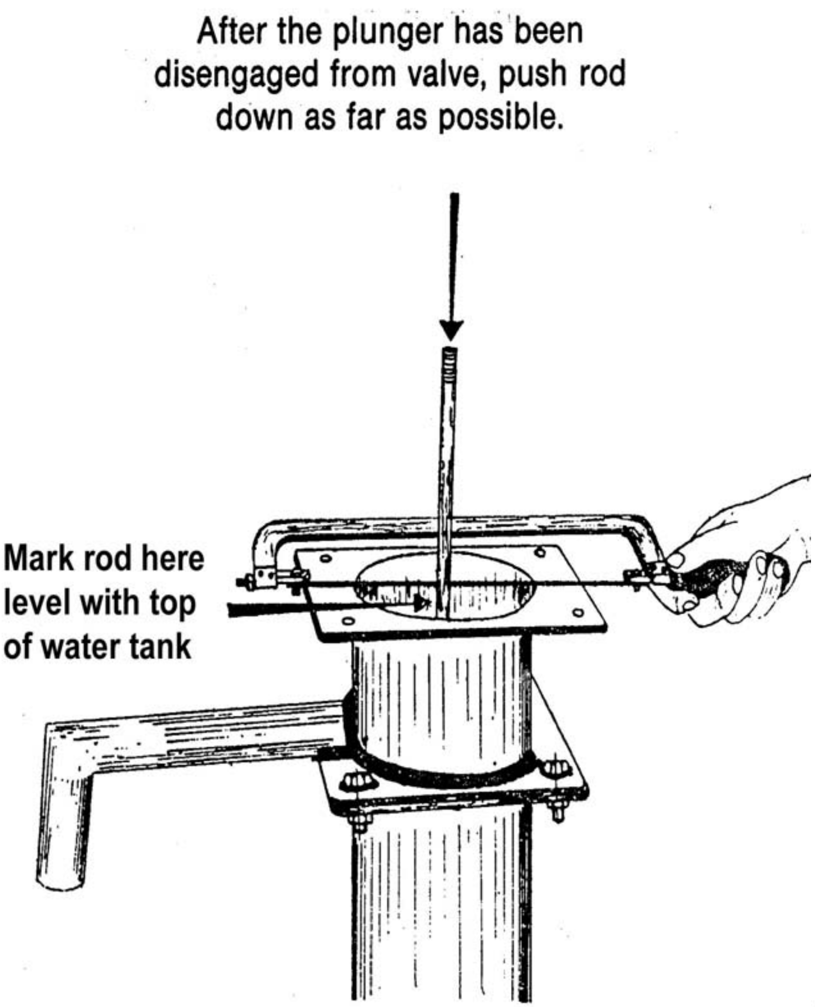


Step 26

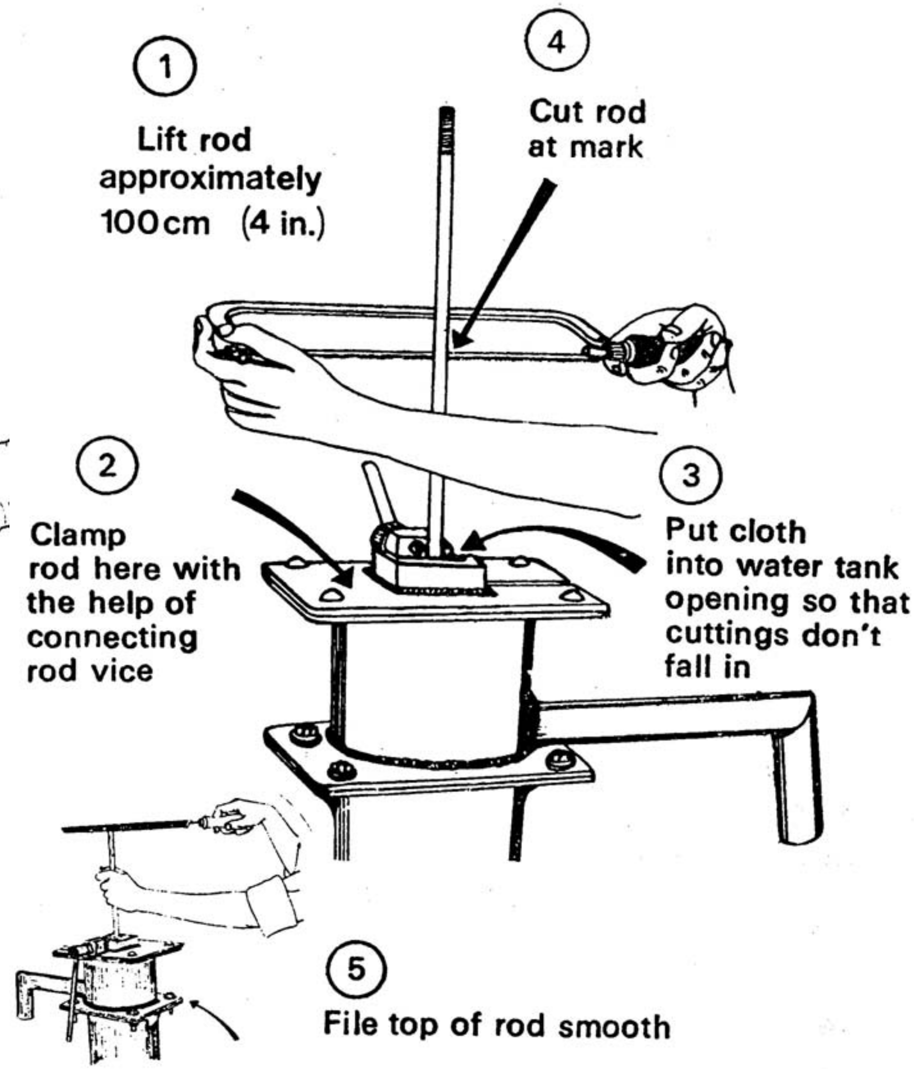
Screw the Connecting Rod Lifter to the last rod. Seat the valve assembly in the bottom of the cylinder by pressing downward on the connecting rod lifter. To disengage the plunger from the valve, turn the connecting rod lifter in the opposite direction to rotation of the hands of a clock (counter-clockwise).



Step 27



Step 28

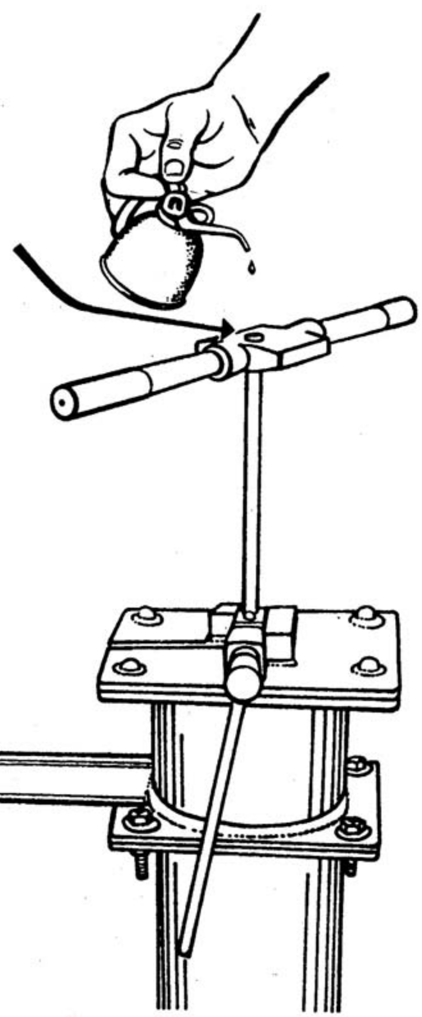


Step 29

Leave cloth in water tank

(1) Thread connecting rod for at least 50 mm (2"). Make sure the thread is clean and true.

Check thread with check nut. You must be able to screw the nut all the way down the thread by hand.



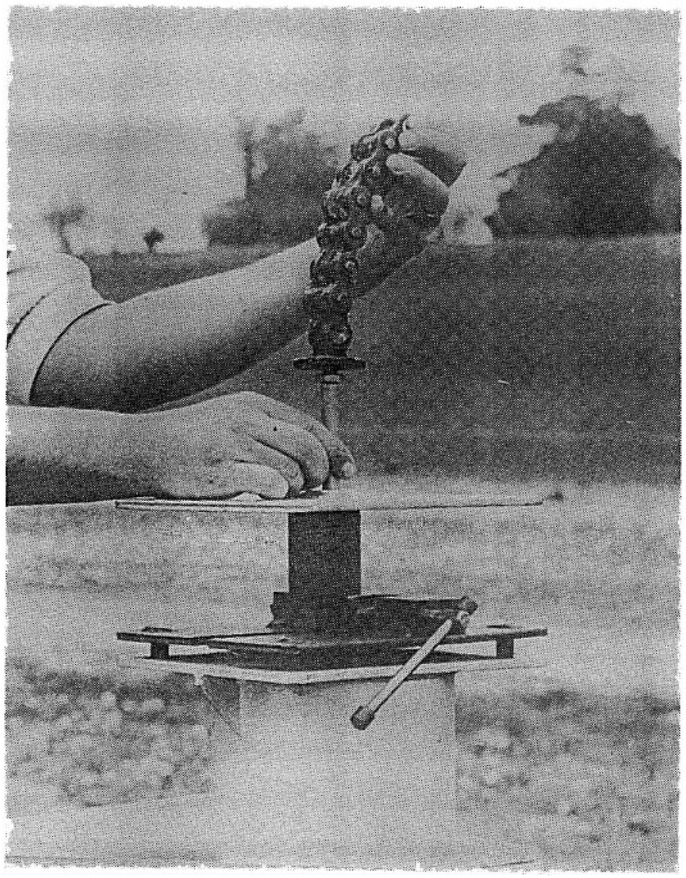
(2) Now remove cloth

Step 30

Remove connecting rod lifter. Place plate over pump rod and screw nut onto rod.

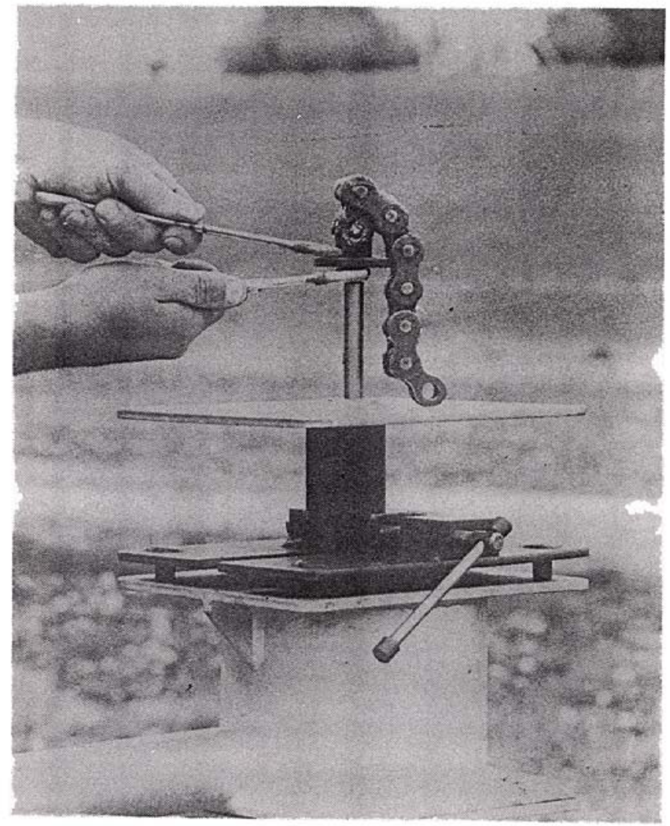
Step 31

Screw the chain coupler fully onto the pump rod.



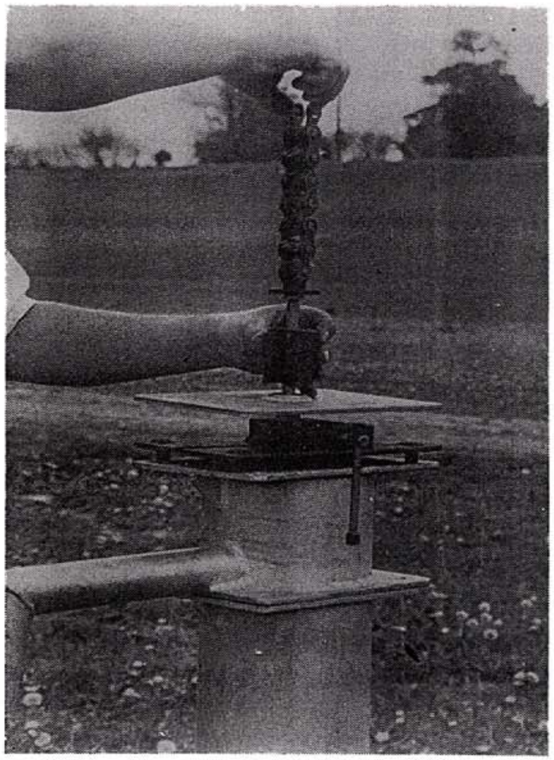
Step 32

Tighten nut against chain coupler using open end wrenches.



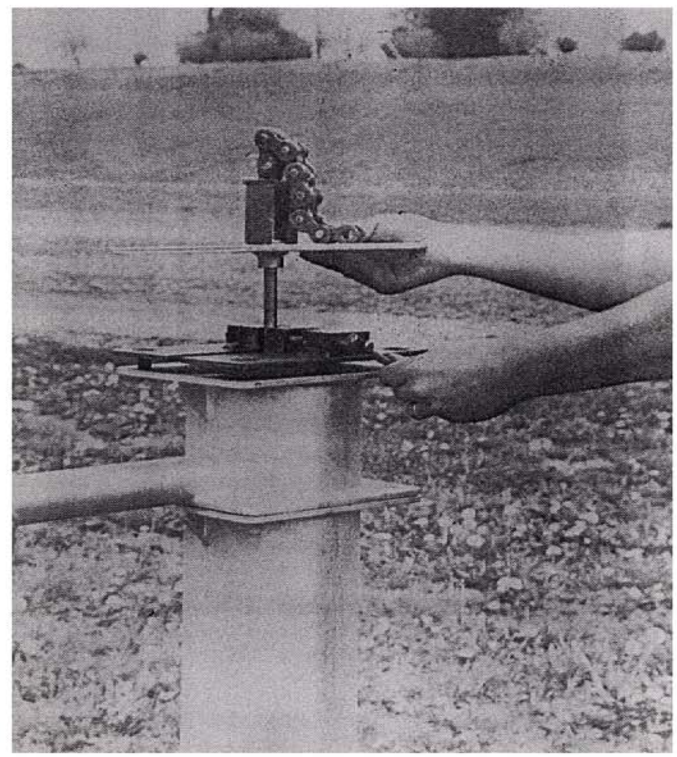
Step 33

Place the raising tool of the chain attachment on the additional flange.



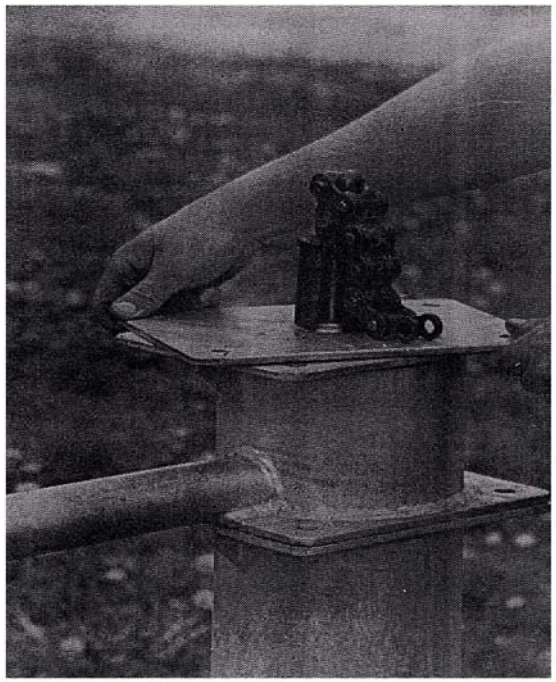
Step 34

Raise the flange and remove the rod vice.



Step 35

Lower the additional flange onto the water chamber.

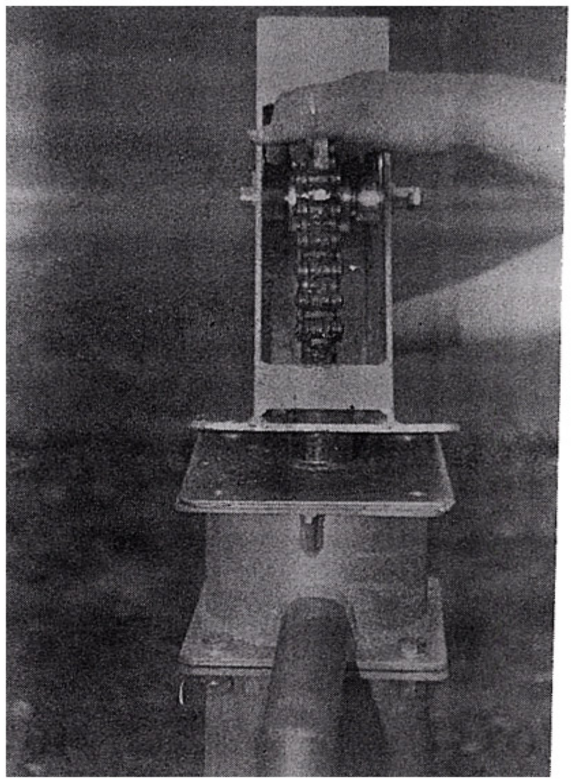


Step 36

Align the bolt holes in flange and water chamber. Insert chain through hole in bottom of pump head.

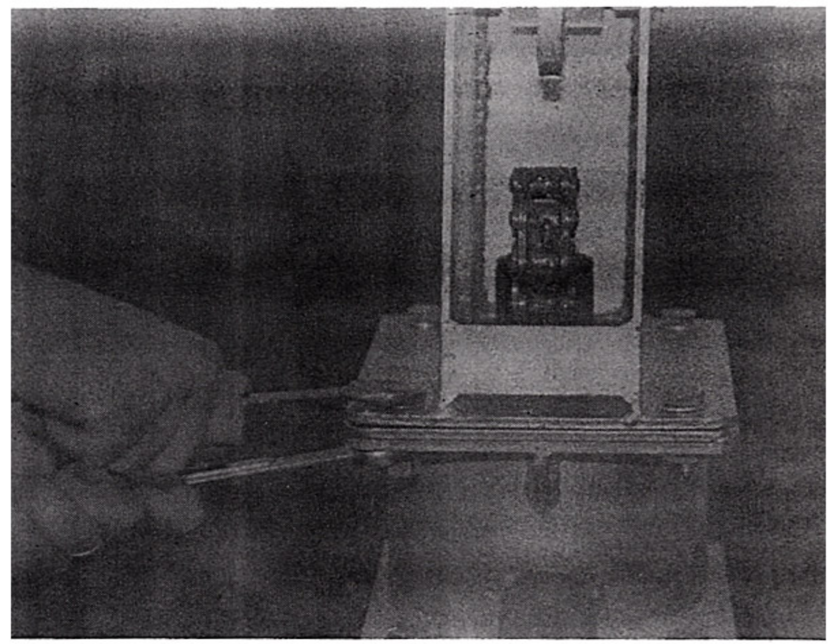
Step 37

Place the pump head on the water chamber so that the chain the chain supporting tool goes through the hole in the bottom of the pump head.



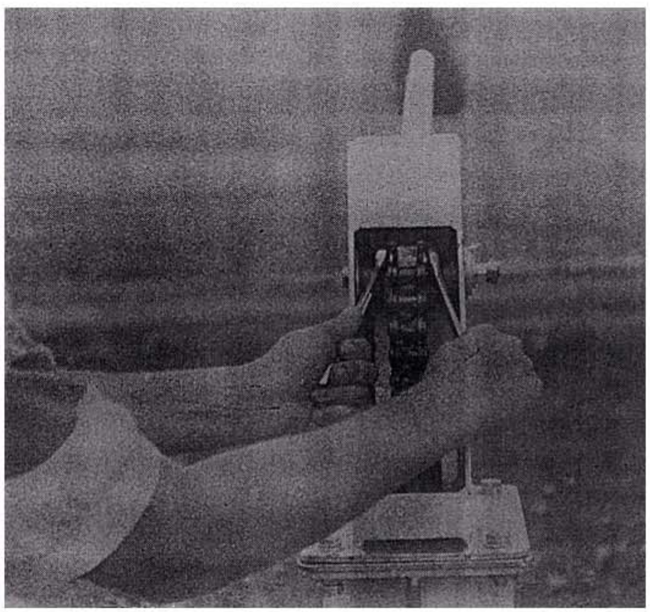
Step 38

Tighten the bolts and the nuts with the wrenches.



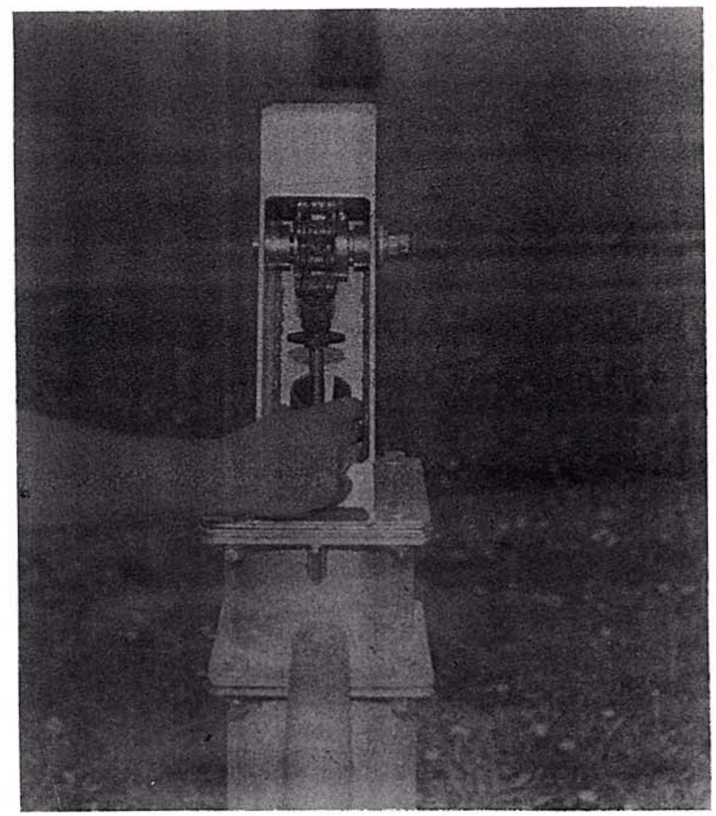
Step 39

Bolt chain to handle. Use self-locking nut. Tighten fully — use two spanners.



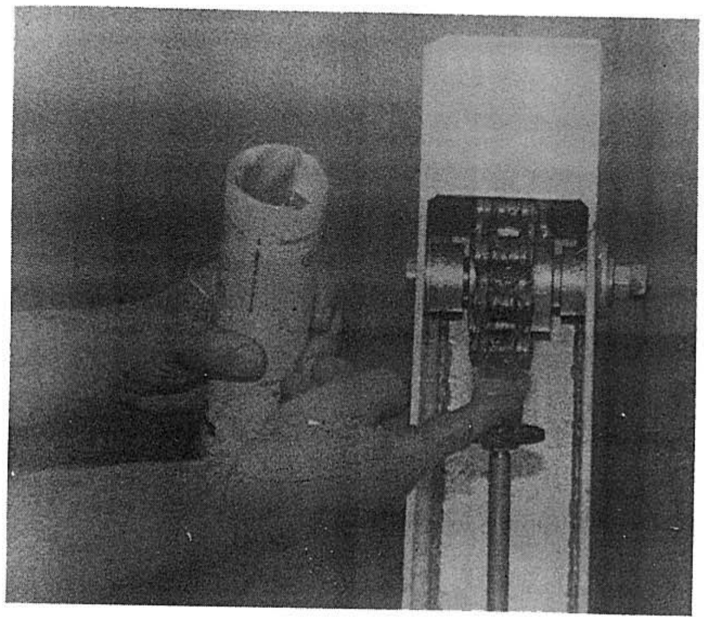
Step 40

Push handle down and remove holding tool from under chain.



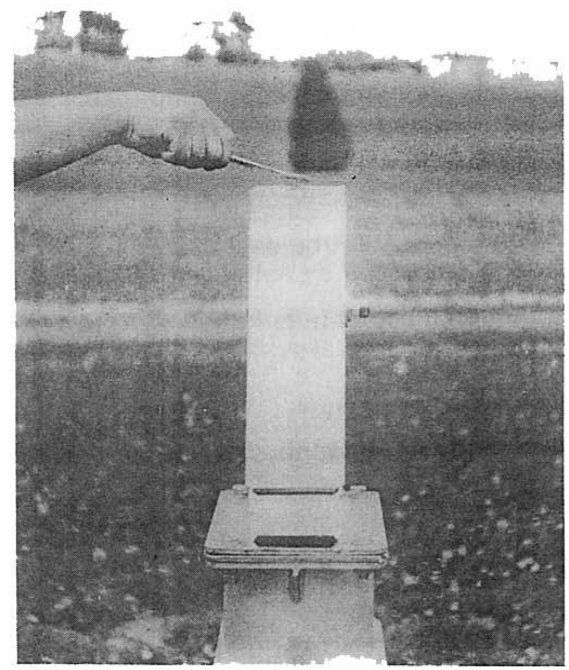
Step 41

Put grease on the chain.



Step 42

Install the cover and bolt tightly.



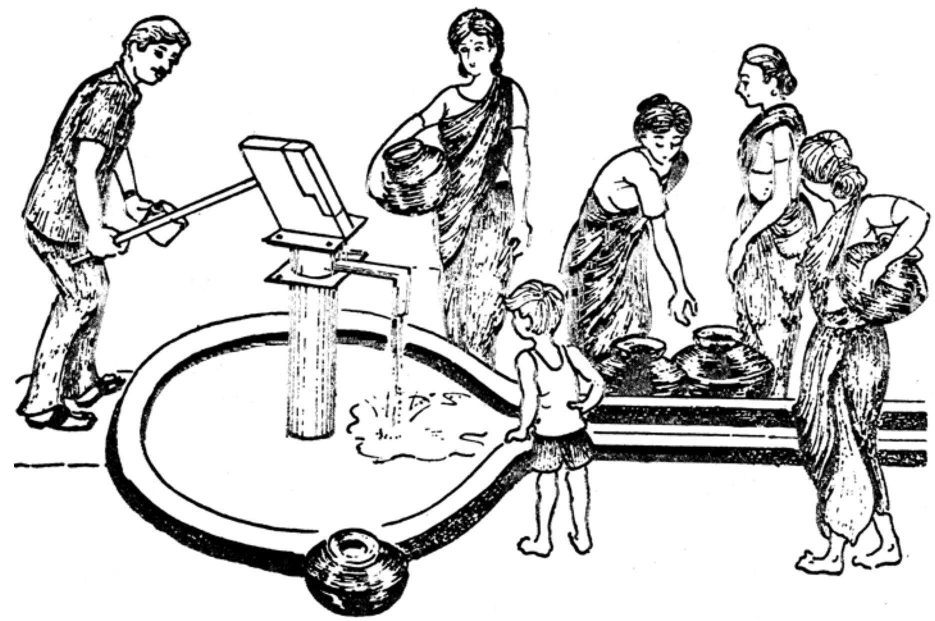
Step 43

Now make sure that...

- When you pump, the handle touches the top and bottom stops. **If it does not,** then remove head and check the setting of the top connecting rod. Refer to step 16.
- Connecting rod moves up and down freely in guide bushing. **If it does not,** adjust intermediate flange.
- You have threaded chain coupling fully onto connecting rod and you have tightened the lock nut fully.
- You have tightened axle nut and lock nut fully and the axle is firmly retained.
- You have tightened chain anchor bolt and nut fully.
- You gave greased the chain.
- All 8 flange bolts are tight and you have tightened the lock nuts fully.
- You have left nothing inside the head.
- Make sure that all tools and unused parts are clean and loaded on the vehicle.

Step 44

Pump one hundred times
to get clean water.



Check the water. Is it clear of
oil, jointing compound, dirt ?
If water is not clean, pump another 100 times.

The water may taste strange to the villagers.
Explain to them that it is good, safe water.
They will soon get used to it.

FINAL CHECK LIST

Before you leave, have you…

- Talked to the villagers about the importance of the handpump for their health?
- Purged the tubewell?
- Checked the quality and taste of the water?
- Explained to the villagers that the water from the handpump may taste different, or strange? You must explain that they should still drink it because this water is safe. They will get accustomed to the new taste soon.
- Given the villagers the address of your office, so that they can inform you if the pump breaks down?
- Made a note of any problems with the tubewell or the handpump, so that you can report them to the District Executive Engineer?

CHLORINATION

Occasionally tubewells get polluted. This may happen if there are natural calamities such as floods, or if the handpump platform gets damaged or destroyed. You will then need to disinfect the tubewells by chlorination.

How to chlorinate a tubewell:

- Remove the four bolts from the lower part of the handpump's water tank. Lift water tank and clamp in the raised position.
- Pour chlorine solution into open end of pedestal. Local health authorities can tell you how much chlorine to use.
- Lower water tank and bolt it back to pedestal. Tighten fully.
- Pump; stop pumping when the water smells strongly of chlorine.
- The handpump must not be used for **at least one hour**. But it is better if the handpump is not used for 6 hours or more. So, ask the villagers not to use it until the next day.
- The next day, pump until the taste of chlorine is just noticeable in the water.
- Collect a sample of the water. Use a sterile bottle. Seal the bottle and label it.
- Send the sample for bacteriological examination.

IMPORTANT NOTE:

INSTALLING PUMP ON OLD TUBEWELLS

So far, this manual has explained how to install handpumps on **new** tubewells. You may, however, also have to install handpumps on **old** tubewells. Before you install a handpump on an old tubewell, take these additional steps:

1. With the help of a string and weight, measure the depth of the tubewell.
2. At what depth do you plan to install the handpump cylinder? Compare the two depths.

   There is no problem if you find that the bottom of the tubewell is at least 3 m (10 ft) **below** the cylinder. In this case, install the handpump as explained in the manual.
3. But if you find that the bottom of the tubewell is **less** than 3 m (10 ft) below the cylinder, or that it is **above** the cylinder, it means that the bore is filling up with mud or sand.

   In that case, arrange for the drilling team to visit the site in order to flush the bore.

   Afterwards, measure the depth of the tubewell again. Install the handpump only after all mud and sand has been removed from the bore.

SHALLOW WELL INSTALLATIONS

Use of the chain link in the pump necessitates balancing the handle weight with adequate weight of connecting rod and water column.

When well cylinder is installed at depths from 18 m to 25 m, use 16 mm diameter rod for all except the top rod, which connects to the chain link.

MAINTENANCE OF THE MARK II HANDPUMP

To ensure a continuous supply of safe drinking water to the people of those villages where the Mark II Handpumps have been installed, regular maintenance is required which would prevent breakdowns and ensure good continuous working of the handpumps. The Block Inspector-cum-Mechanic and the District Mobile Maintenance Team should do regular preventive maintenance. The Block Inspector-cum-Mechanics should look after a maximum of 50 handpumps in a well-defined area. His contribution to the good functioning of the 3-tier maintenance system will depend on his regular visits to the handpump sites in his area. His task should be confined to the maintenance of the aboveground structure, i.e. the pumphead, platform and drainage. When he anticipates a major breakdown on a handpump, he informs the District Mobile Maintenance Team. He does the same when he encounters, on his daily rounds, a broken-down handpump. In doing so he will, thus, provide to the District Engineer the relevant information pertaining to the operational condition of the handpumps in his area of operation.

The following are the checkpoints a mechanic should undertake for each and every handpump he visits on a weekly basis:

1. Tighten all nuts and bolts of the aboveground mechanisms; replace bolts, nuts and washers if necessary.

2. Open up front cover of tophead. Clean the insides of tophead; apply a little oil to chain.
3. Operate the handpump and check whether the discharge is normal. This will assess the working condition of the cylinder piston and foot-valve. If discharge is not normal, inform District Engineer for necessary repairs by District Mobile Team.
4. The Mark II Handpump is galvanized and should require no rust prevention. If necessary, clean with wire brush and sandpaper and apply anti-rust paint.
5. If any cracks have developed in the platform, fill these with cement mixture. Check if handpump pedestal is firm in its foundation; if loose, inform District Mobile Maintenance Team for corrective action.

The District Mobile Maintenance Team:

The team will undertake, on a regular basis, preventative as well as corrective maintenance of the handpumps in the area. A District Mobile Maintenance Team should look after 500 to 600 Mark II Handpumps. This means that each handpump can be checked once or twice a year for a complete overhaul for above-ground and below-ground mechanisms, as well as to rectify any shortcomings on platform, drainage and soakage pit.

For preventive maintenance, the District Mobile Maintenance Team should follow the procedures indicated as follows:

STEP-BY-STEP PROCEDURE FOR PUMP OVERHAUL

Before you move out of any handpump site, consult the Mark II Handpump Installation Manual for checklist of tools and materials, and use this checklist to ensure you have all tools and materials with you on the vehicle.

When starting the work, ensure that all the tools you will require are within hand's reach to facilitate you work. You can spread out a gunny bag or some other material upon which you can put the tools to protect them from dirt. You should do the same for all the handpump components you are going to remove. Ensure here also that the components are kept off the ground and protected from any dirt. Also, a pipe stand can be used to keep the G.I. pipes and rods off the ground.

DISMANTLING THE PUMP

1. Remove top-head front cover.
2. Disconnect handle from chain by removing the nyloc nut and bolt.
3. Take out handle-axle. While removing, use axle punch to protect axle threading and remove handle from top-head.
4. Remove top-head flange bolts.
5. Insert one pipe-lifting spanner into the holes provided in the top-head and lift top-head (see step 21 of Manual).
6. Fit the connecting rod vice onto the water chamber top flange and tighten.
7. Remove chain and chain lock nut and remove top-head.
8. Remove bottom flange and water tank bolts.

9. Lift water tank by using lifter pipe and lifting spanners.
10. Fit heavy duty clamp and tighten, and remove water tank.
11. Disassemble rising main and connecting rods. Remove only 3 m lengths at a time.
12. While removing the pipes and rods ensure that you place these off the ground (see step 9 of Manual). Continue doing so until the entire belowground assembly has been removed from the tubewell.
13. Disconnect cylinder from the last pipe.
14. Check all the pipe threads; clean out the threads by using a wire brush. Remove any dirt and rust from the pipes by using sandpaper or wire brush. Rethread if necessary. If any pipe is damaged, replace. Ensure that all pipe couplings are intact and fit properly.

CONNECTING RODS

15. Check all the connecting threads and couplings. Clean out threads with wire brush. Remove all the dirt and rust from the rods by using sandpaper or wire brush. Fit lock nuts. If any connecting rod lock nut is missing, replace. Rethread connecting rods if required. Check each rod for straightness. If rods are bent, try to straighten them. If not possible, replace.

CYLINDER OVERHAUL

16. Unscrew top and bottom reducer caps using heavy-duty clamp and wrench. Remove piston on assembly and foot-valve. Check piston and foot valve assembly and replace any worn out components. Replace if necessary, leather cup-washers, leather sealing ring, rubber seating etc. Check for cracks, which may have developed in the cylinder components. Replace parts if necessary. Assemble complete cylinder assembly.

IMPORTANT:

Check cylinder assembly for any leakage. Put cylinder in a bucket of water and move piston up and down. When cylinder is full of water, hold up and check whether any water is seeping through the foot-valve. If so, re-open cylinder, check piston and foot valve assembly again for correct assembly and proper tightening. If necessary, replace the foot valve. Lock the upper valve seat and rubber seat retainer of the cylinder by punching at right angle at circumference of mating surface.

PUMP BODY OVERHAUL

17. Clean inside of water chamber and top-head. Remove all dirt and rust inside and outside handpump body. Unit is galvanized, but if necessary remove rust with wire brush or sandpaper and apply anti-rust paint.

Assemble the handpump following the handpump installation procedures, as shown in the Manual.

PLATFORM CHECKING

As you know, the Mark II Handpump ought to be installed with a proper concrete platform and pedestal. A handpump platform is essential since: (1) it provides the foundation for the pump pedestal; (2) it acts as a hygienic seal; (3) prevents any surface water percolation into the tube-well and hence excludes any contamination of the tube-well water. Therefore, special attention should be paid to the platform conditions and (1) you should check for cracks, which may have developed in the platform, and (2) check whether the pump pedestal is tightly secured to its foundation.

If the platform has any cracks, or if the pedestal is loose, do the following:

18. Fill up cracks in the platform with cement. Make sure that exposed platform brickwork is covered again with cement plaster.
19. To reinforce the handpump pedestal base, dig out a circular space of minimum 5 cm wide and 10 cm deep around pedestal base and fill this up with a 1:2:4 concrete mixture. Whenever cement plaster for concrete mixture is re-applied to an existing platform, curing time should be allowed which is normally 7 days. Disconnect the handle from the chain so that nobody can operate the pump and ask the villagers not to use the handpump for the duration of the prescribed time. The required setting time can be reduced if quick setting compound is mixed with the cement and concrete mixtures. When quick setting compound is used, 24 hours curing time is required.

CHLORINATION OF THE TUBEWELL

20. Upon completion of the overhaul job, the tubewell should be chlorinated. Follow the chlorination instructions as indicated on page 38 of the manual.

REMEMBER

- No dirt should enter the tubewell while lowering pipes and rods since this may seriously contaminate the tubewell water.
- To clean all the handpump components thoroughly before assembly.
- To tighten all nuts and lock nuts as well as connecting rod couplings and lock nuts and riser pipe couplings.

TOOL REQUIREMENTS FOR DISTRICT MOBILE TEAM

Each District Mobile Team (D.M.T.) should be provided with the following three tool kits:

1. Took kit for small district level workshop.
2. Tool kit for hand pump repairs in the field.

3. Special tool kit of Mark II installation and repair tool

1. Tool kit for District Level Workshop

These tools are meant for use at the small workshop to be established at district levels, for reconditioning of handpump components. The G1 pipes, connecting rods retrieved from the existing tubewells can be reconditioned: i.e. cutting and/or rethreading (50 mm. Long at both ends) fitting of pipe couplings, connecting rod couplings and lock nuts. Particularly, the cylinder has to be reconditioned at this small workshop since this requires thorough checking of the entire assembly (for cracks which may have developed on older cylinders; properly fitting good quality leather buckets replacing worn-out parts). The cylinder should be tested at the workshop also against possible leakage of valves. A good number of reconditioned cylinders, pipes and rods should always be kept in stock. The district level workshop is operated by the mobile team members. Alternatively, an extra mechanic could be put in charge of this reconditioning work.

The aim of the workshop is to establish gradually a service exchange system, where reconditioned handpump components are used as "new" items during handpump repairs.

In this way, handpump repairs in the field will considerably be expedited as well as minimize hasty, and often incorrect, handpump repairs which may result in unnecessary breakdowns necessitating another visit to the same handpump site within a short time span. The tools are kept at the district level office.

2. Tool kit for handpump repairs in the field

The complete set of tools should always be with the mobile team when handpump repairs are undertaken. The kit comprises of all basic tools required for any kind of handpump repairs.

Although repairs in the field should be preferably be kept to the minimum using instead reconditioned handpump components, the set contains some of the similar tools as for the district workshop, enabling the D.M.T. to meet any handpump contingency.

3. Special toolkit for Mark II Handpumps

These tools have been developed specifically for Mark II installation and repair. These tools will decrease installation time by 70%, simplify the installation procedure and increase safety.

The kit contains:

Item	Description	Qty.
1	Combination Lifting Spanner 1 1/4" to 1 1/2"	3
2	Pipe Lifter	1
3	Crank Spanner-17MM x 19MM	2
4	Connecting Rod Vice	1
5	Connecting rod Lifter and Axle Pin Holding Spanner	1
6	Handle Axle Punch	1
7	Heavy Duty Clamp	1

The tools except 1 & 7 are fitted in a toolbox.

Tool Kit for District Workshop and District Mobile Team for Installation, Reconditioning & Maintenance of Mark II Handpumps.

Standard Tools:

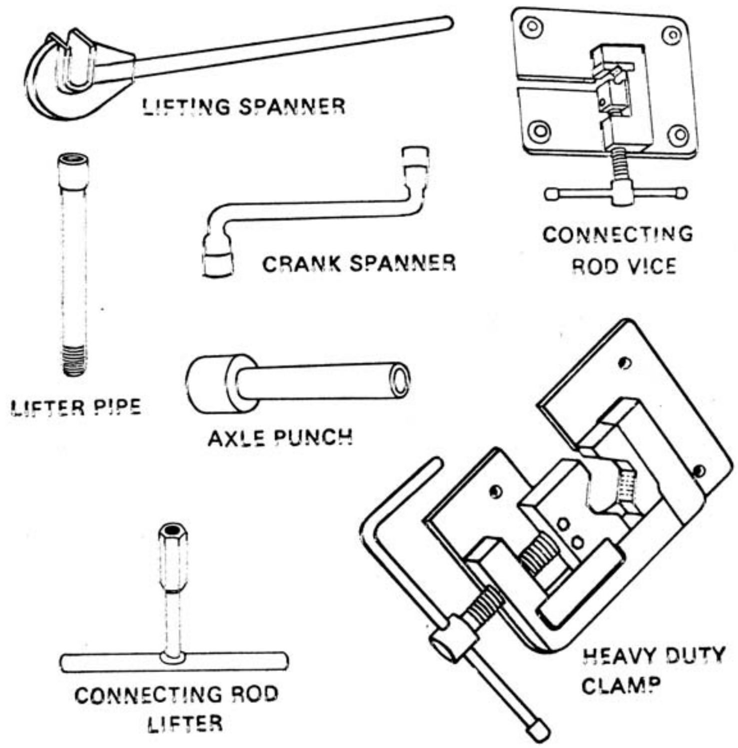
ITEM

1. Pipe wrench 24 inch
2. Adjustable spanner 12 inch
3. Open ended spanner 17 mm x 18 mm
4. Open ended spanner 18 mm x 19 mm
5. Hacksaw with spare blade 10 inch – 12 inch
6. Flat file 10 inch fine
7. Half round file 10 inch fine
8. Stock & die to cut 1 ¼ inch BSP or 1 ½ inch BSP threads with spare die
9. Stock & die to cut M12 x 1.75 threads with spare die
10. M12 x 1.75 tapset with handle
11. Small screwdriver
12. Large screwdriver
13. Engineer's hammer ½ kg
14. Spirit Level
15. Wire brush & sandpaper
16. Chisel
17. Tape measure 2 m
18. Oil can
19. Grease gun
20. Bench vice

Special Tools:

ITEM

1. Lifting spanner (3 Nos.)
2. Lifter pipe
3. Crank spanner (17 mm x 19 mm) (2 Nos.)
4. Connecting rod vice
5. Connecting rod lifter
6. Axle punch
7. Heavy duty clamp



There are seven special tools for Mark II Handpumps. These tools should be used by District Mobile Maintenance Teams when installing or repairing Mark II Handpumps.

TOOL No. 1 – LIFTING SPANNER – set of 3 Nos.

Use to lower or lift the rising main. These Lifting Spanners will not slip or break.

The Lifting Spanners fit both 1 ¼ inch BSP and 1 ½ inch BSP sizes of pipe.

Use 2 Lifting Spanners to lower or lift up to 30 m (100 ft) of rising main.

Use 3 Lifting Spanners if the rising main is longer than 30 m (100 ft).

DO NOT use your pipe wrenches for lifting or lowering the rising main.

TOOL No. 2 – LIFTER PIPE – 1 No.

Use to lower or lift the water tank and rising main together.

1. Remove pump head.
2. Thread Lifter Pipe into top of rising main coupling inside water tank.
3. Grip Lifter Pipe with two or three Lifting Spanners.
4. Lift or lower entire assembly.

TOOL No. 3 – CRANK SPANNERS

Use a pair of Crank Spanners to tighten or loosen the flange bolts and check nuts, and the chain anchor belt.

TOOL No. 4 – CONNECTING ROD VICE – 1 No.

Use to clamp the Connecting Rod before you cut or thread the rod. This will avoid bending of the Connecting Rod.

1. Place Connecting Rod Vice on top of flange of water tank.
2. Tighten Vice (Vice has own handle) to grip Connecting Rod.
3. Cut and thread Connecting Rod.

TOOL No. 5 – CONNECTING ROD LIFTER –1 No.

Use this tool:

A. To *lift Connecting Rod*, thread tool onto Connecting Rod, then lift upwards.

B. To *test pumping action,* fit Lifting Spanner handle through the Connecting Rod Lifter, and pump.

C. To *tighten/loosen axle,* grip axle head between the two flats on the tool and tighten/loosen axle nut with a Crank Spanner.

TOOL No. 6 – AXLE PUNCH – 1 No.

Use to drive axle out of the bearings without damaging axle threads.

1. Remove Axle nut.
2. Fit Axle Punch over threaded end of axle.
3. With a hammer, tap Axle Punch lightly until axle is partially removed.
4. Pull axle out by hand.
5. Pull out Axle Punch.

TOOL No. 7 – HEAVY DUTY CLAMP – 1 No.

Use this tool:

A. To lift or lower rising main pipe.

B. To open reducer caps on the cylinder body.

NOTE: Remember to arrange for:

1 tin Jointing Compound, for pipe joints

1 tin Chasses Grease, to lubricate chain

1 tin Oil or cutting fluid, for cutting threads

Cotton waste or cleaning rag

Cement, metal and sand for the platforms.

Tools for the mason: shovel, trowel, bucket, etc.

Recommended Spares for each Mark II Handpump for Two years Operation:

Spares for Pump Head:	*Qty. (Nos.)*
1. Hexagonal bolts M 12 x 1.75 x 40	4
2. Hexagonal nuts M 12 x 1.75	8
3. Washer M 12	8
4. Hexagonal bolts M 10 x 1.5 x 40	2
5. Nyloc nuts – M 10	1
6. Axle	1
7. Bearing	2
8. Sockets	2
9. Chain with coupling	1
10. Bolt & nut for cover M 12 x 1.75 x 20	1
11. Front cover	1
12. Spacer	1
13. Special washer for axle	1

Spares for Cylinder:	
1. Leather cup washer	2
2. Leather sealing ring	3
3. Rubber seating (big)	1
4. Rubber seating (small)	1

Spares for Connecting Rod:	*Qty. (Nos.)*
1. Hexagonal coupling M 12 x 1.75 x 50	2
2. Connecting Rod 12 M dia & 3 m length	1

Note: The spares mentioned above for Pump Head may not be required for actual maintenance; these are only an estimate to take care of possible pilferage.

Note:

In case of need, the following spare sub-assemblies are also available from Dempster Industries.

(1) Conversion head assembly
(2) Handle assembly
(3) Water tank assembly
(4) Pedestal
(5) Cylinder assembly

APPENDIX F.2

Mecate Rope Pump

Private Sector Technology Transfer from Nicaragua to Ghana

*2002. The Rope Pump: Private Sector Technology Transfer from Nicaragua to Ghana.
*Published by the Water and Sanitation Program (WSP).

Water and Sanitation Program

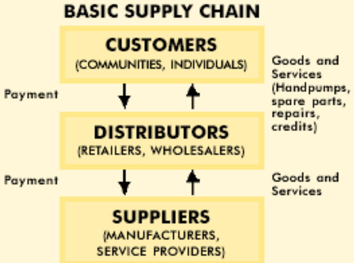
An international partnership to help the poor gain sustained access to improved water supply and sanitation services

Developing Private Sector Supply Chains to Deliver Rural Water Technology

The Rope Pump: Private Sector Technology Transfer From Nicaragua to Ghana

In the rural water supply and sanitation sector, goods and services (technology, training, repair services, financial and technical services, and facility management) are supplied to customers through a supply chain from manufacturers, importers, and service providers through a network of distributors. Payment flows in the opposite direction.

BASIC SUPPLY CHAIN



The Supply Chains Initiative is a global initiative led by the Water and Sanitation Program. Collaborating partners include government departments, NGOs, and bilateral and multilateral agencies. The aim of this initiative is to develop practical tools that enable and encourage the private sector to provide goods and services related to rural water supply and sanitation. The initiative's first phase will focus on increasing the understanding of the dynamics of the private sector supply chains for handpumps, spare parts, and sanitation equipment.

Users of Ghana with their new pump.

Summary

The Nicaraguan rope pump has stimulated widespread interest throughout Central America due to its low cost, efficiency, durability and low maintenance needs. The pump is based on a centuries-old design that was refined during the 1980s and 1990s. Suitable for use at either a community or family level, the pump operates as well as other, more expensive pumps such as the Afridev and India Mark II at groundwater depths of up to 50 meters. The Swiss Agency for Development and Cooperation (SDC), seeing the potential for 'South-South' technology transfer of the pump, supported the principal Nicaraguan manufacturer, Bombas De Mecate S.A. (BOMESA), in setting up a Technology Transfer Center between 1996 and 1998. Working with counterparts in the West African country of Ghana, supported by the Water and Sanitation Program (WSP), BOMESA has successfully established the capacity to both produce and install the pump in that country. The experience has shown the great potential for such a transfer to bring a low-cost, reliable pump to countries where handpumps can help meet the challenge of delivering sustainable rural water supply.

SUPPLY CHAINS Links to sustainability 5

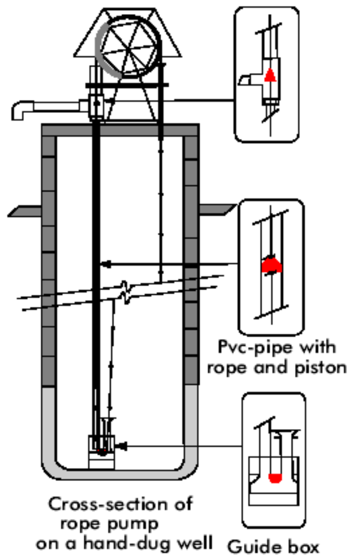
Background

In rural areas in many countries, the dispersed nature of the population has made handpumps the technology of choice for potable water supply. Handpumps require lower upfront costs and less maintenance than piped networks. Despite these natural advantages, throughout the 1960s and 1970s it became clear that 'Northern' handpump technologies were not always applicable to a developing country framework. Pump repair and maintenance often proved problematic, as did the availability of imported parts. In the early 1980s, the WSP Handpumps Project sought to address these issues by developing the concept of 'Village Level Operation and Maintenance' (VLOM) – a concept that was based on the involvement of the user community in maintenance, and technology suited to this. The donor community invested considerable resources in developing 'appropriate technology' pumps such as the India Mark II and Afridev pumps. However, these pumps still pose problems of high cost and sometimes complex supply chains for parts; in addition, there are always some types of repair that the users cannot carry out (see Supply Chains Series No. 2: Afridev Handpumps in Pakistan).

The rope pump is a centuries-old technology, with records of designs from ancient China and turn-of-the-century France. It has been used successfully for supplying both communities and individual families, but until recently was typically suitable only for groundwater depths of less than 10 meters. Whereas these older designs suffered in the long-run from their limited applicability, the rope pump – now found throughout Nicaragua and elsewhere in Central America – has overcome these initial design limitations. This achievement has made the rope pump comparable in functionality to more expensive pumps.

The Rope Pump in Nicaragua

The majority of Nicaragua's 4.5 million people live on lowlands bordering the Pacific. Surface water is typically polluted and there is widespread use of groundwater sources, whether these be community or family wells. In the early 1980s, a Belgian technician developed a variation on the classical rope pump design for use in irrigation. In 1988 the government showed interest in developing the pump for drinking water purposes. By 1990 a private firm, Bombas De Mecate S.A. (BOMESA), had started manufacturing a version of the pump. Production since that time has increased dramatically, and BOMESA now manufactures over 150 pumps per month. Another private manufacturer, Taller Lopez-Erlach (TLE), has a similar output, and there are



BOX 1: THE ROPE PUMP

The principal elements of the rope pump are a pulley wheel, a rope with pistons attached, a pipe that enters the well, and at the base of this pipe, a guidance device for the rope. As the crankshaft is turned the rope drags the pistons up the pipe, trapping the water above them and ejecting it at the surface. The pump functions well at groundwater depths of up to 50 meters.

Due to the simple and sturdy design of the pump, maintenance needs are very limited and can easily be handled by the community or local artisan. The rope itself is the most likely part to break down, and can either be easily and cheaply replaced locally or patched up without difficulty. Makeshift repairs do not significantly detract from pump performance.

at least a dozen other small-scale participants in the market.

It is estimated that over 7,500 pumps were sold and installed in Nicaragua in 1999, and that over half of Nicaragua's rural population have heard of the pump – a result apparently due to the extensive marketing that the pump has received by the manufacturers. The marketing as well as the receptive attitude of the Nicaraguan government have been important factors in the pump's success.

In the early 1990s the Nicaraguan government added the locally produced rope pump to the list of pumps selected for use in the rural water sector, even though at that time the technology was still under development. This is an example of the government's attitude which facilitated the emergence of the market for the rope pumps despite the fact that the other pumps, all imported, received support from external agencies in all aspects of the distribution and maintenance chains.

THE HISTORY OF THE ROPE PUMP IN NICARAGUA

Early 1980s: Belgian technician develops a variation on the classical rope pump design.

1988: The government develops pump for drinking water purposes and post-hurricane demand swells rapidly.

1990: Bombas De Mecate S.A. (BOMESA) commences manufacturing, selling to low-income rural families.

1995: Private sector demand has been augmented by interest from ENACAL and NGOs. IRC report on Nicaraguan Rope Pump.

1996-98: Technology Transfer Division created within BOMESA – produces transfer kit.

1999: Production surpasses 7,500 pumps a year. Ghanaian authorities and others investigate transfer possibilities.

Supply

Both BOMESA and TLE manufacture a variety of pumps for communal and family use. TLE sells self-assembly kits that are put together and sold by local workshops. Installation can be performed on request by either firm, but tends to be prohibitively expensive. As a result, BOMESA provides an installation manual and a short training course to customers. TLE, on the other hand, maintains a network of installers throughout the country whom they recommend to pump buyers. The buyer pays the installer directly.

Demand

Demand for the pumps comes from three sources: rural families, NGOs and donors, and government organizations. During the first couple of years of production, private clients made up the majority of BOMESA's customers, while subsequently demand from donors, NGOs and government has expanded rapidly. Private clients, however, remain a significant source of revenue for both major manufacturers.

Affordability

One of the keys to the rapid spread of the rope pump in Nicaragua has been its low cost allied to its reliability and low maintenance needs. A study performed for the WSP found that the annual maintenance cost of the rope pump never exceeded $10 (and in fact was less than $5 in all but one area surveyed). By comparison, the annual maintenance cost for pumps in India – predominantly India Mark IIs – ranged between $59 and $107.

The upfront cost of the rope pump is also significantly less than for Afridev or India Mark II pumps. The same study found that in Nicaragua India Mark II pumps sold for $750 (with similar prices for Afridev pumps) while the equivalent rope pump sold for $110. The imported pumps are harder to install and maintain and rely on imported parts, whose delivery may be problematic. Therefore, in Nicaragua for wells at a depth of less than 60 m, the rope pump has been preferred to either imported pump.

In addition to its efficiency, low cost and reliability, the rope pump's simple technology means that, given a rudimentary in-country manufacturing base, it can be both produced domestically and repaired locally, features which contribute greatly to sustainability.

The Rope Pump in Ghana

The Government of Ghana launched the National Community Water and Sanitation Program in 1991 to accelerate access of rural communities to sustainable water and sanitation services. The agency responsible – the Community Water and Sanitation Agency (CWSA) – works with the active participation of communities, NGOs and the private sector. Communities receive government assistance in improving their services, but are ultimately responsible for the operation and maintenance of their facilities, drawing upon the private sector for goods and services.

CWSA presently supports the installation of four types of pumps, but finds its reliance on imports for both the pumps and spare parts to be problematic. CWSA would thus like to promote the local manufacture of lower cost pumps in Ghana. With the financial support of a World Bank-supported project, CWSA staff made a short visit to Nicaragua in May of 1999 to investigate the potential for transferring the rope pump to Ghana. Representatives met with the Technology Transfer Division of BOMESA, a division that has been set up with the help of both ENACAL and SDC. They were suitably impressed by the efficiency, reliability, low cost, and availability of rope pumps in Nicaragua and saw potential for private sector development of the pump in Ghana.

CWSA wanted to nurture a local production base for the pumps within Ghana, initially supporting several local manufacturers through guaranteed purchase schemes and by undertaking outreach work with communities in order to install a number of trial pumps. If successful, the project could be scaled up. The manufacturing of the pumps would be entirely privately financed, allowing a sustainable production, installation and repair base to develop.

Following the CWSA visit to Nicaragua, the WSP agreed to fund a three-phase transfer process. Under the first phase in 1999, BOMESA helped identify several Ghanaian workshops suitable for the production of the rope pump. The local availability of materials required for manufacturing was confirmed while some parts (such as the ceramic guide box and the pistons) were supplied from Nicaragua during the initial phases of the transfer. The capacity for producing these parts in-country was found to exist and will ensure long-term local supply. Production has now commenced in Ghana and several pumps have been successfully installed. Representatives of the workshops in Ghana have since visited Nicaragua to undergo further training in both technical and marketing issues.

The key to this technology transfer has been its 'South-South' nature. Many of the characteristics of the rural areas and the local private sector are similar in the two countries, and prospects for establishing a financially self-sustaining private sector base for the production, installation and repair of rope pumps in Ghana is good. The World Bank, WSP and CWSA have been deeply involved during the early stages of the transfer. It is expected, however, that both demand and supply for rope pumps will flourish independently after this initial support.

The production of the first pump in Sindigo, Savelugu District, Northern Region of Ghana.

Technology Transfer: The Potential

Unlike many past examples of technology transfers from the 'North', the transfer for the rope pump from Nicaragua to Ghana offers great promise. It is based on the idea that the private sector of different countries can come together in mutually beneficial cooperation to manufacture and sell the rope pump. The partnership offers great potential for the private sector in both countries – with cooperation, both sides can benefit from the demand for a low-cost, reliable handpump.

With respect to the specifics of the technology transfer and capacity for companies to launch this type of product, several significant factors are outlined here.

THE TRANSFER PROCESS

The transfer process from Nicaragua to Ghana consisted of three phases.

Phase I (November 15 to November 26, 1999):
Technical assistance provided via correspondence and a two-week visit by BOMESA to the Ghanaian authorities to help with selection of suitable manufacturers, confirm the availability of materials, supply technology transfer manuals, and help commence production.

Phase II (February 7 to February 10, 2000):
BOMESA hosted two Ghanaian technicians in Nicaragua for further training, dealing with the automatization of production, marketing techniques and financial management.

Phase III (June 19 to June 30, 2000):
Installation of the trial-run of 100 pumps in Ghana, further technical assistance from BOMESA covering quality control, branding and steps to develop a durable relationship between the Nicaraguan and Ghanaian manufacturers. This phase is to be followed by an evaluation of the pump's local acceptance and performance in early 2001.

Institutional climate

The favorable institutional climate was a key element in the successful emergence of the pump in Nicaragua and is important in determining the potential for a successful transfer elsewhere. Resistance from the government or other agencies makes it very difficult for sustainable private sector provision to take root.

Supply

A local supply chain needs to be created with demonstrable links to the community. It should also be short enough so that rope pump manufacturing will form an important part of revenue and encourage long-term commitment by the supplier. Given the low technology nature of the pump, the appropriate pump manufacture materials should be easily available in the country. Installation and repair requirements also need consideration, with the Nicaraguan example providing a useful model.

Due to the simplicity of the pump, a specific supply chain for spare parts is not required. A majority of the parts can usually be found at the local grocer or hardware shop.

Quality control

Quality control of the raw materials, manufacturing, and the installation of the pump are key elements of success. A standard of quality should be agreed to and applied by the principal producers in a country/region. The experience in Nicaragua has shown that inferior reproductions of the pump by 'artisans' that are cheaper and below standard can damage the reputation of the pump (see Supply Chains Series No.1: The Treadle Pump: An NGO Introduces a Low-cost Irrigation Pump to Bangladesh).

Demand

A WSP study *Rural Water Supply in Nicaragua: The Rope Pump* indicates that demand should be high wherever there are a large number of low-income rural households with no access to piped distribution water. A tradition of using family wells for drinking water is helpful, as this will facilitate rope pump adoption and lower the capital cost where existing wells can be used. Evidence also indicates that in the beginning the role of state extension agencies, NGOs, and donors will be extremely important in mobilizing demand for the pump. BOMESA stresses that a successful trial installation, with product quality assured and followed by marketing and information campaigns, is of great importance. Demand must prove sustainable once initial support is withdrawn.

Financing

Financing and willingness to pay for producers is critical to the success of the transfer. If manufacturers require seed capital, governments or donors could provide this. This should take place preferably in the initial phases only. In Ghana a guaranteed initial purchase provided the incentive to develop initial production capacity.

The need for independent cost recovery by the private operators cannot be overstated. If this is only achieved through distortions in the market, due to government or donor intervention, then production will remain dependent upon such distortions.

Support to marketing

Marketing and promotion are extremely important in establishing the demand for the pump. To promote sustainability, the manufacturer should incorporate costs of marketing into the price of the pump. Careful branding is also important. However, a large promotion campaign is a heavy cost for the manufacturer and the industry to assume alone. A recent study by SDC, *Poverty Alleviation as a Business*, recommends the launching of a significant promotion and marketing campaign for the pump. The study suggests that this could be done as a public investment and that such a campaign could be a good investment for donor water and sanitation programs.

Conclusion

The Nicaraguan rope pump has significant potential. Its low cost, efficiency and reliability have given it high social acceptance in Nicaragua and elsewhere, while its low-technology nature permits local manufacturing. Experience has shown that it exhibits significant potential for 'direct' technology transfer from company-to-company and should be of great interest to policy-makers and the private sector alike. Several key issues remain regarding the dissemination and transfer of this technology:

- the role of external agencies, the government, and the private sector in supporting the process
- the types of arrangement between private companies from Nicaragua and other companies in the world to facilitate dissemination and assure a sustainable high quality production
- the extent of demand and potential for similar transfers in other countries.

These and others issues will be discussed in two upcoming events:

1) May 2001: Workshop in Nicaragua, organized by the Handpump Technologies Network (HTN), SDC, and BOMESA in partnership with the International Resource Center (IRC) and the WSP. The workshop is designed to inform national rural water supply policy-makers and international decision-makers of the rope pump technology. Structured actions to support the rope pump technology transfer process will be also defined. The workshop should increase the visibility of the rope pump across the international rural water supply sector.

2) End of 2001: Workshop in Ghana, led by CWSA, private sector investors and others with the support of the WSP. Opportunities for stimulating market demand throughout West Africa will be discussed.

WILLINGNESS TO PAY

Willingness to pay by users is also important, and this has been found to exist where financing for them is available. The national public utility (ENACAL) in Nicaragua has implemented a pilot project with CARE and SDC in which micro-credit is made available for the purchase of family rope pumps. This pilot, carried out in a poorer area of the country, has shown that the population exhibits both a willingness and a capacity to repay the loan for the pump in one year. Demand for the pump for both domestic and small-scale gardening purposes exists, provided that suitable credit is available. It is also notable that the pump is not regarded as an inferior good – a "product for the poor". Many middle-class families also use it, and ownership comes with no social stigma.

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Other publications in this series:

1. The Treadle Pump: An NGO Introduces a Low-cost Irrigation Pump to Bangladesh
2. Afridev Handpumps in Pakistan
3. Arsenic Mitigation in West Bengal and Bangladesh
4. The Growth of Private Sector Participation in Rural Water Supply and Sanitation in Bangladesh

February 2001

The Water and Sanitation Program is an international partnership to help the poor gain sustained access to improved water supply and sanitation services. The Program's funding partners are the Governments of Australia, Belgium, Canada, Denmark, Germany, Italy, Japan, Luxembourg, the Netherlands, Norway, Sweden, Switzerland, and the United Kingdom; the United Nations Development Programme, and The World Bank.

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APPENDIX G

Pumping Requirements Example Calculation

Water for the World

Determining Pumping Requirements

Technical Note No. RWS. 4.D.2

Before pumping requirements can be determined, a water source must be identified, water use must be estimated based on the population to be served and the type of system must be chosen. If a Level 1 or 2 system, described in "Methods of Delivering Water," RWS.4.M, is selected, then much less water is required and pumping costs will be lower.

The World Health Organization recommends that provision be made for a minimum of forty (40) liters of water per person per day if a communal distribution point is used. Where water must be hauled, fifteen (15) liters per person per day should be provided. For water piped to the home, one hundred (100) liters or more per person per day is desirable.

The next most important factor in determining pumping requirements is the pumping head. This head includes the difference in height between the pump and the highest point in the system, usually the storage tank, and the head needed to overcome friction. See Figure 1. Part of the head may be fixed, as in the case of the location of the pump and the storage tank, and part may vary depending on the difference in flow or pipe size. Since pipe size can be changed, as can flow by using longer or shorter pumping times, these are the primary variables in designing a pumping system. Provision must be made for friction requirements of valves, bends and meters, if used.

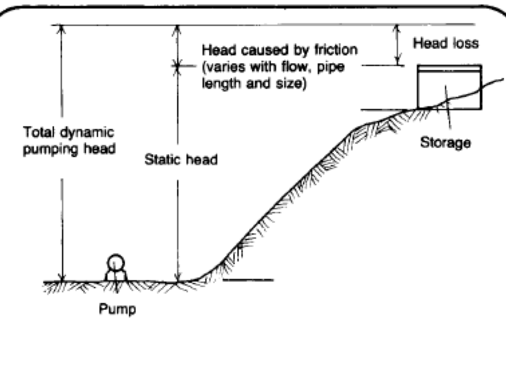

Figure 1. Total Dynamic Pumping Head

Useful Definitions

DRAWDOWN - The distance between the water table and the water level in a well during continued pumping.

HEAD - Difference in water level between the inflow and outflow ends of a water system.

HEAD LOSS - The head required to overcome friction.

PUMPING HEAD - The height to which a pump must raise water including the height of the highest point in the system plus the equivalent height to overcome friction; expressed as meters of water.

STATIC HEAD - The difference in meters between the elevation of the pump and the highest point in the system, usually the top of a storage tank, to which the pump must raise water.

STATIC WATER LEVEL - The water level in a well when the pump is not operating.

TOTAL DYNAMIC HEAD (TDH) - The total energy which the pump must provide to lift water to the pump, to raise water to the maximum elevation, and to meet all friction requirements; expressed in meters of water.

When a water source has been selected and the type of system chosen, then quantity, pumping distance and elevation of storage can be measured or calculated. Once these are known and flow is estimated, a pipe diameter can be selected. This information is then used to determine pump size.

Windmill Pumping Systems

Windmills can be used to pump water in quantities ranging from 380-12000 liters per hour depending on wind speed, windmill diameter, pump size and pumping head or lift. Wind speed determines pumping capacity. Although windmills are under development which can pump at much lower windspeeds, the most widely available windmill pumps at its maximum rate at wind speeds of 25-32km per hour. At 16km per hour, the capacity is reduced 37 percent and at 20km per hour it is reduced 22 percent. The wind normally blows at the most usable speeds for only a few hours per day and this must be taken into consideration. If the wind blew strong enough to pump water for six hours per day, then the quantity of water produced would be 2400-73000 liters per day.

Since wind speeds vary over the course of a year, this must be taken into account. It is advisable to provide for a storage tank near the windmill to provide for times when the wind does not blow.

To design a windmill system, the quantity of water needed must be determined, the total dynamic head (TDH) found and the expected wind speed predicted. These data can then be used to size the system.

Example: A village of 150 people have decided to develop a Level 2 water system with several distribution points near the population center. Water is available in a well 30m deep. Wind energy measurements have been taken and it has been determined that the wind speed is between 25 and 32km per hour an average of three hours per day; 16km per hour for six hours per day; and 20km per hour for four hours per day. What size windmill and pump cylinder would be required?

1. Calculate the amount of water needed: 150 people x 50 liters per day = 7500 liters. Next, convert average wind speed to effective wind speed. This is done by multiplying the number of hours the wind blows times the percentage of the windmill pump's full power.

Wind speed	Percent of full power	Hours/ day	Equivalent hours
25-32 km/hr	100%	3	3.0
20 km/hr	78%	4	3.1
12 km/hr	63%	6	3.8
		Total	9.9 hours

The wind will have optimum power 9.9 hours per day.

2. Then find the liters of water per hour required to meet the community's needs.

$$\frac{\text{Water required}}{\text{Pumping time in hours}} = \frac{\text{7500 liters}}{\text{9.9 hrs}} =$$

758 liters/hour

Once the quantity of water required per hour and the elevation to which the water must be lifted are known, the windmill can be sized using Table 1.

Table 1. Windmill Data

Pump cylinder size in mm	Capacity in liters/hour		Elevation to which water can be raised SIZE OF FAN					
	2m	2.4-4.8m	2m	2.4m	3m	3.6m	4.2m	4.8m
44	397	568	40	56	85	128	183	305
48	473	681	37	53	79	119	171	280
50	492	719	29	43	66	98	140	229
57	681	984	23	34	52	76	110	180
64	852	1230	20	29	43	64	91	149
70	1003	1457	17	24	37	55	79	130
80	1211	1779	14	21	30	47	67	110
83	-	2082	-	-	27	40	56	93
89	1666	2438	11	15	23	35	49	81
95	-	2763	-	-	20	30	44	70
100	2158	3142	8	12	18	26	38	61
108	-	3558	-	-	16	23	34	55
114	2744	3975	6	9	14	21	30	49
121	-	4429	-	-	-	19	27	43
127	3407	4921	5	8	11	17	24	40
146	-	6435	-	-	-	12	18	30
152	-	7098	-	5	8	12	17	26
178	-	9653	-	-	6	9	12	20
203	-	12492	-	-	4	7	9	15

In the example, the pumping rate of 758 liters/hour and the pumping head of 30m can almost be met by a windmill with a 2.4m diameter fan and a 50mm cylinder. To determine that this is true, look down column 3 in Table 1 to the number 719 liters/hour. The number is in the column under 2.4-4.8m. Looking to the left under column 1, pump cylinder size, the capacity corresponds to a cylinder size of 50mm. However, 719 liters/hour is somewhat below the needed capacity. Therefore, looking down column 3 the next greatest capacity is 984 liters/hour which is sufficient to supply community needs. A pipe cylinder of 57mm would be needed for this windmill as shown in column 1.

Now the exact size of the windmill fan can be determined. Columns 4-9 represent the height which water can be raised by a certain sized fan. In our example, water needs to be raised 30m. Look across the fourth row where the figure 984 liters/hour is located until a figure of 30 or greater is found. In column 5, the number 34m is found under a fan size of 2.4m. Therefore, a 2.4m diameter fan is needed. If a relatively high storage tank and friction requirements mean the water must be raised over 34m, the next largest diameter fan should be chosen.

Electric Pumping Systems

There are many combinations of electric pumps available and often the pump and motor come as a unit. There are two main methods of selecting electric pumps. One is to design the system and select the pump from manufacturers' catalogs. The other is to give the supplier complete details of the pumping conditions and have him determine the pump needed. The information needed to select an electric pump includes:

1. Quantity of water required.

2. Pumping head.

3. Type of power available, number of phases, and voltage type (AC or DC).

4. Size of well. If applicable, depth to water, drawdown, and production capability.

5. Special considerations such as limited pumping times and elevation above sea level.

Quantity of water required. Identify the number of people to be served and the type of system to be used. From this, estimate the total quantity of water needed.

Pumping head. Provide the elevation difference between the pump and the high point in the system and the head losses due to friction.

Type of power available. Determine what is available from the electric utility organization and any restrictions that may be placed on the use of the electricity. This is important because restrictions may limit the amount of power available and in some locations electricity may not be available 24 hours per day.

Size of well. If a well is to be used, its diameter, the depth to water, and the drawdown at the rate it is pumped are required.

Special considerations. These include such items as any operation limitations, pump controls desired, elevation of the water source above sea level, and other considerations which might influence pump size.

For flows in the range of .3-13 liters per second, pumps are readily available and can be selected directly from manufacturers' catalogs. In sizing the pump, an optimum pumping time is 10-12 hours. Pumping can be timed manually, by using a time clock or by using other types of pump controls. If the system is to be manually operated, the pumping rates must be based on the availability of an operator. In any case, the pumps should be sized for population increases expected over the next five years. The pump should meet the maximum daily water requirement supplemented by elevated storage. If no other information is available, use a factor for maximum daily use of twice the average use.

Calculating Pumping Requirements

The following example describes how to determine pumping requirements:

A pump is to be selected for a Level 3 system with distribution to every household in a village with a current population of 500 people. There are no commercial operations or institutions in the village and livestock will obtain water from a nearby stream. No growth is expected in the next five years. There is a dug well 20m deep with the static water level at 10m. Pumping tests show the well can produce 5 liters of water per second with a drawdown of 3m. Single phase, 120/230 volt AC electricity is available. Because of electric line size, the electric utility agency has limited motor size to 5 HP. The site is not favorable for use of a windmill and no water that could be delivered by gravity flow is available. The storage tank will be located on a hill 300m from the well and the top of the tank will be 20m above the top of the well.

It is always a good idea to draw a graphic representation of the information prior to designing a solution. This example is illustrated in Figure 2.

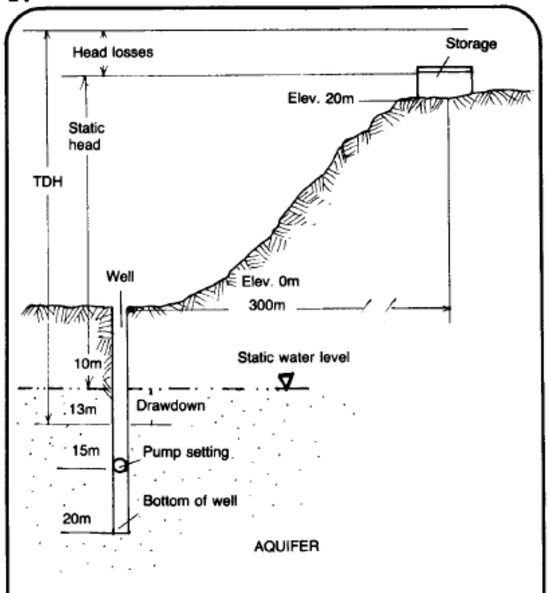

Figure 2. Graphical Representation of Data

Worksheet A shows the steps described below in sizing the system.

Step 1. Estimating present water needs.

Since the system is to serve only the village, the present estimated needs are 50000 liters per day.

Step 2. Estimating future water needs.

Worksheet A provides a way to estimate future water needs if other information is not known. In this case, future needs are 200000 liters of water per day.

Step 3. Estimating storage needs.

Convert liters to cubic meters to find the storage needed. In this example, storage is $200m^3$.

Step 4. Pump production requirements.

Pumps and motors are more efficient and last longer if they have relatively long interrupted pumping cycles. This also permits the use of lower yield wells. In this case, 4.6 liters per second are required for a 12 hour pumping cycle at the design life of 20 years.

In comparing the water available, 5 liters per second, with that required, 4.6 liters per second, the source appears to be sufficient for the design period of 20 years.

Step 5. Determine pipe size.

The selection of a pipe size is influenced by the cost of pumping. The larger the pipe size, the lower the pumping costs so larger pipe sizes should be selected where the cost of energy is high. Since energy requirements are directly related to the velocity of water in the pipe, the costs can be minimized by using a relatively slow velocity. A velocity of 0.75m per second is considered optimal and is used in this formula.

The exact calculated pipe size is 88mm. A pipe could be selected from available sizes of 80mm or 100mm. Friction losses could be calculated for each size and a total dynamic head (TDH) found. If the friction head were approximately 10 percent or less of the TDH for one or both pipes, then either would be suitable. In this case, 100mm pipe was chosen as being more readily available.

Step 6. Motor size.

The horsepower requirements were calculated based on needs for 20 years. It is better to size pumps for a shorter period as they only have an estimated life of five to ten years.

If a ten year design were used and the water required were estimated to be 50 percent of the 20 year use, the pump would be designed for a flow of 2.3 liters/second and the necessary HP would be:

$HP = \frac{2.3 \times 33.5}{76 \times .6}$ (recalculated for lower friction loss) =

$\frac{77.05}{45.6} = 1.68$ HP (use 1 3/4 HP)

4

Diesel oil or gasoline powered pumps. The information needed for a diesel oil or gasoline powered pump is the same as for an electric pump. The primary difference is in the power required. This will be greater due to inefficiencies in the drive mechanism to the pump. It is best to rely on the pump supplier for this data.

Worksheet A. Designing a Small Water Pumping System

1. Estimated present water needs in liters:

	Number of		Unit use		Total
Population	Persons 500	x	100	=	50,000
School	Students ____	x	____	=	____
Church	Attendees ____	x	____	=	____
Commerical	____	x	____	=	____
Large animals (cows)	____	x	____	=	____
Small animals (sheep)	____	x	____	=	____
Public watering fountains	____	x	____	=	____

Total present water needs = 50,000

2. Estimated future water use:
   Use a 20 year design life. If no better information is available, use a population growth of 2 times the present population and an increase in animals of 1.25 times the present number. In addition, assume an increase in the rate of use of 2 times.

   Population Present use 50,000 x 4 = 200,000 liters

   Institutions & public fountains Present use ____ x 2 = ____ liters

   Animals Present use ____ x 1.25 = ____ liters

   Total future water use = 200,000 liters/day

3. Storage reservoir:
   Take the future water use and convert it to cubic meters

   Reservoir = $\frac{200{,}000}{1000}$ liters = 200 m^3

4. Pump production requirements:
   Determine the estimated pumping rate in liters/second

   Total daily demand = $\frac{200{,}000 \text{ liters}}{43{,}200 \text{ second}}$ = 4.6 liters/second

   If a pumping time is not given use 12 hours or 43200 seconds

5. Determine pipe size from pump to storage:

5

Worksheet A. Designing a Small Water Pumping System (continued)

Pipe diameter $d = 1.3 \sqrt{m^3 \text{ per second}}$

$= 1.3 \sqrt{.0046 \text{ liters/second}} =$ __0.088__ m

Convert meters to mm: 1000 x __0.088__ m = __88__ mm

Round mm calculated to available pipe size: d = __100__ mm

(Note: This method of pipe sizing is based on limiting the velocity of water in the pipe to 0.75 m/second).

6. Motor size:
To calculate the pump size, first find the total dynamic head (TDH).

TDH = static head + friction losses

Friction losses
a. Determine head required to overcome friction.

Fitting	Number	x	Equivalent length	=	
Gate valve	1	x	2.7	=	2.7 m
Elbow, 90°	2	x	13.2	=	26.4 m
Elbow, 45°	____	x	____	=	____ m
Tee (straight through)	____	x	____	=	____ m
Tee (through side)	____	x	____	=	____ m
Swing check valve	1	x	38.2	=	38.2 m

Total equivalent length __67.3__ m

Length of pipe from pump to storage = __300__ m

Total pipe length = __367__ m

Friction loss = $\frac{367}{1000}$ m x __4.2__ head loss per 1000/m = __1.5__ m

b. Determine static head
Static head = elevation at top of storage - pump elevation
= __-13__ m - __20__ m = __33__ m

c. TDH = a+b = Friction loss + static head = __1.5__ + __33__ = __34.5__ m

d. Horsepower requirements:

$$\text{Horsepower} = \frac{Q \times H}{76\ e}$$

Q = Flow in liters/second
H = System head in meters
76 = Constant
e = Pump efficiency

Horsepower = $\frac{\text{4.6 liters/second}}{76 \times e}$ x __34.5__ meters = __3.48__ HP

Round to nearest available motor size = __3.5__ HP

If the efficiency is unknown, assume 60 percent, 0.6.

6

APPENDIX H

Pipe Friction Loss Tables

Friction Loss

TECHNICAL DATA

PLASTIC PIPE:

FRICTION LOSS PER 100 FT.

GPM	GPH	3/8″		1/2″		3/4″		1″		1¼″		1½″	
		Ft.	Lbs.	Ft.	Lbs.	Ft.	Lbs.	Ft.	Lbs.	Ft.	Lbs.	Ft.	Lbs.
1	60	4.25	1.85	1.38	.60	.356	.155	.11	.048				
2	120	15.13	6.58	4.83	2.10	1.21	.526	.38	.164	.10	.044		
3	180	31.97	13.9	9.96	4.33	2.51	1.09	.77	.336	.21	.090	.10	.043
4	240	54.97	23.9	17.07	7.42	4.21	1.83	1.30	.565	.35	.150	.16	.071
5	300	84.41	36.7	25.76	11.2	6.33	2.75	1.92	.835	.51	.223	.24	.104
6	360			36.34	15.8	8.83	3.84	2.69	1.17	.71	.309	.33	.145
8	480			63.71	27.7	15.18	6.60	4.58	1.99	1.19	.518	.55	.241
10	600			97.52	42.4	25.98	11.27	6.88	2.99	1.78	.774	.83	.361
15	900					49.68	21.6	14.63	6.36	3.75	1.63	1.74	.755
20	1,200					86.94	37.8	25.07	10.9	6.39	2.78	2.94	1.28
25	1,500							38.41	16.7	9.71	4.22	4.44	1.93
30	1,800									13.62	5.92	6.26	2.72
35	2,100									18.17	7.90	8.37	3.64
40	2,400									23.55	10.24	10.70	4.65
45	2,700									29.44	12.80	13.46	5.85
50	3,000											16.45	7.15
60	3,600											23.48	10.21

Friction Loss

TECHNICAL DATA

PLASTIC PIPE:

FRICTION LOSS PER 100 FT.

GPM	GPH	2″		2½″		3″		4″		6″		8″		10″	
		Ft.	Lbs.	Ft.	Lbs.	Ft.	Lbs.	Ft.	Lbs.	Ft.	Lbs.	Ft.	Lbs.	Ft.	Lbs.
6	360	.10	.044												
8	480	.17	.073												
10	600	.25	.108	.11	.046										
15	900	.52	.224	.22	.094										
20	1,200	.86	.375	.36	.158	.13	.056								
25	1,500	1.29	.561	.54	.234	.19	.083								
30	1,800	1.81	.786	.75	.327	.26	.114								
35	2,100	2.42	1.05	1.00	.436	.35	.151	.09	.041						
40	2,400	3.11	1.35	1.28	.556	.44	.191	.12	.052						
45	2,700	3.84	1.67	1.54	.668	.55	.239	.15	.064						
50	3,000	4.67	2.03	1.93	.839	.66	.288	.17	.076						
60	3,600	6.60	2.87	2.71	1.18	.93	.406	.25	.107						
70	4,200	8.83	3.84	3.66	1.59	1.24	.540	.33	.143						
80	4,800	11.43	4.97	4.67	2.03	1.58	.687	.41	.180						
90	5,400	14.26	6.20	5.82	2.53	1.98	.861	.52	.224						
100	6,000			7.11	3.09	2.42	1.05	.63	.272	.08	.036				
125	7,500			10.83	4.71	3.80	1.65	.95	.415	.13	.055				
150	9,000					5.15	2.24	1.33	.580	.18	.077				
175	10,500					6.90	3.00	1.78	.774	.23	.102				
200	12,000					8.90	3.87	2.27	.985	.30	.130				
250	15,000							3.36	1.46	.45	.195	.12	.051		
300	18,000							4.85	2.11	.63	.275	.17	.072		
350	21,000							6.53	2.84	.84	.367	.22	.095		
400	24,000									1.08	.471	.28	.121		
500	30,000									1.66	.720	.42	.182	.14	.059
550	33,000									1.98	.861	.50	.219	.16	.071
600	36,000									2.35	1.02	.59	.258	.19	.083
700	42,000											.79	.343	.26	.112
800	48,000											1.02	.443	.33	.143
900	54,000											1.27	.554	.41	.179
950	57,000													.46	.198
1000	60,000													.50	.218

2

Friction Loss

TECHNICAL DATA

STEEL PIPE:

FRICTION LOSS PER 100 FT.

GPM	GPH	⅜″		½″		¾″		1″		1¼″		1½″		2″	
		Ft.	Lbs.	Ft.	Lbs.	Ft.	Lbs.	Ft.	Lbs.	Ft.	Lbs.	Ft.	Lbs.	Ft.	Lbs.
1	60	4.30	1.85	1.86	.80	.26	.11								
2	120	15.00	6.45	4.78	2.06	1.21	.52	.38	.16						
3	180	31.80	13.67	10.00	4.30	2.50	1.08	.77	.33						
4	240	54.90	23.61	17.10	7.35	4.21	1.81	1.30	.56	.34	.15				
5	300	83.50	35.91	25.80	11.09	6.32	2.72	1.93	.83	.51	.22	.24	.10		
6	360			36.50	15.70	8.87	3.81	2.68	1.15	.70	.30	.33	.14	.10	.04
7	420			48.70	20.94	11.80	5.07	3.56	1.53	.93	.40	.44	.19	.13	.06
8	480			62.70	26.96	15.00	6.45	4.54	1.95	1.18	.51	.56	.24	.17	.07
9	540					18.80	8.08	5.65	2.43	1.46	.63	.69	.30	.21	.09
10	600					23.00	9.89	6.86	2.95	1.77	.76	.83	.36	.25	.11
12	720					32.60	14.02	9.62	4.14	2.48	1.07	1.16	.50	.34	.15
15	900					49.70	21.37	14.70	6.32	3.74	1.61	1.75	.75	.52	.22
20	1,200					86.10	37.02	25.10	10.79	6.34	2.73	2.94	1.26	.87	.37
25	1,500							38.60	16.60	9.65	4.15	4.48	1.93	1.30	.56
30	1,800							54.60	23.48	13.60	5.85	6.26	2.69	1.82	.78
35	2,100							73.40	31.56	18.20	7.83	8.37	3.60	2.42	1.04
40	2,400							95.00	40.85	23.50	10.11	10.79	4.64	3.10	1.33
45	2,700									30.70	13.20	13.45	5.78	3.85	1.66
70	4,200									68.80	29.58	31.30	13.46	8.86	3.81
100	6,000											62.20	26.75	17.40	7.48
150	9,000													38.00	16.34
200	12,000													66.30	28.51
250	15,000													90.70	39.00

Friction Loss

TECHNICAL DATA

STEEL PIPE:

FRICTION LOSS PER 100 FT.

GPM	GPH	2½″ Ft.	2½″ Lbs.	3″ Ft.	3″ Lbs.	4″ Ft.	4″ Lbs.	5″ Ft.	5″ Lbs.	6″ Ft.	6″ Lbs.	8″ Ft.	8″ Lbs.	10″ Ft.	10″ Lbs.
10	600	.11	.05	.04	.01										
12	720	.15	.06	.05	.02										
15	900	.22	.09	.08	.03										
20	1,200	.36	.15	.13	.06										
25	1,500	.54	.23	.19	.08										
30	1,800	.75	.32	.26	.11										
35	2,100	1.00	.43	.35	.15										
40	2,400	1.28	.55	.44	.19										
45	2,700	1.60	.69	.55	.24										
70	4,200	3.63	1.56	1.22	.52	.35	.15								
100	6,000	7.11	3.06	2.39	1.03	.63	.27								
150	9,000	15.40	6.62	5.14	2.21	1.32	.57								
200	12,000	26.70	11.48	8.90	3.83	2.27	.98	.736	.32	.30	.13	.08	.03		
250	15,000	42.80	18.40	14.10	6.06	3.60	1.55	1.20	.52	.49	.21	.13	.06		
300	18,000	58.50	25.15	19.20	8.26	4.89	2.10	1.58	.68	.64	.28	.16	.07	.0542	.0235
350	21,000	79.20	34.06	26.90	11.57	6.72	2.89	2.18	.94	.88	.38	.23	.10	.0719	.0312
400	24,000	103.00	44.70	33.90	14.71	8.47	3.68	2.72	1.18	1.09	.47	.279	.1211	.0917	.0398
450	27,000	130	56.42	42.75	18.55	10.65	4.62	3.47	1.51	1.36	.59	.348	.1510	.114	.0495
500	30,000	160	69.44	52.50	22.78	13.00	5.64	4.16	1.81	1.66	.72	.424	.1840	.138	.0599
550	33,000	193	83.76	63.20	27.43	15.70	6.81	4.98	2.16	1.99	.86	.507	.2200	.164	.0712
600	36,000	230	99.82	74.80	32.46	18.60	8.07	5.88	2.55	2.34	1.02	.597	.2591	.192	.0833
650	39,000			87.50	37.97	21.70	9.42	6.87	2.98	2.73	1.18	.694	.3012	.224	.0972
700	42,000			101	43.83	25.00	10.85	7.93	3.44	3.13	1.36	.797	.3459	.256	.1111
750	45,000			116	50.34	28.60	12.41	9.05	3.93	3.57	1.55	.907	.3936	.291	.1263
800	48,000			131	56.85	32.40	14.06	10.22	4.44	4.03	1.75	1.02	.4427	.328	.1424
850	51,000			148	64.23	36.50	15.84	11.50	4.99	4.53	1.97	1.147	.4978	.368	.1597
900	54,000			165	71.61	40.80	17.71	12.90	5.60	5.05	2.19	1.27	.5512	.410	.1779
950	57,000			184	79.85	45.30	19.66	14.30	6.21	5.60	2.43	1.41	.6119	.455	.1975
1000	60,000			204	88.54	50.20	21.79	15.8	6.86	6.17	2.68	1.56	.6770	.500	.2170

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Friction Loss

TECHNICAL DATA

COPPER PIPE:

FRICTION LOSS PER 100 FT.

GPM	GPH	3/8"		1/2"		3/4"		1"		1 1/4"	
		Ft.	Lbs.	Ft.	Lbs.	Ft.	Lbs.	Ft.	Lbs.	Ft.	Lbs.
1	60	6.2	2.7	1.8	.8	.39	.17				
2	120	19.6	8.5	6.0	2.6	1.2	.50				
5	300			30	13	5.8	2.5	1.6	.7		
7	420			53	23	11.0	4.8	3.2	1.4	2.2	.95
10	600					19.6	8.5	5.3	2.3	3.9	1.7
15	900					37.0	16.0	9.9	4.3	6.2	2.7
18	1,080					55.4	24.0	16.1	7.0	6.9	3.0
20	1,200							18.5	8.0	10.4	4.5
25	1,500							27.7	12.0	14.3	6.2
30	1,800							39.3	17.0	18.7	8.1
35	2,100							48.5	21.0	25.4	11.0
40	2,400									30.0	13.0
45	2,700									39.3	17.0

Friction Loss

TECHNICAL DATA

COPPER PIPE:

FRICTION LOSS PER 100 FT.

GPM	GPH	1½"		2"		2½"		3"		4"	
		Ft.	Lbs.	Ft.	Lbs.	Ft.	Lbs.	Ft.	Lbs.	Ft.	Lbs.
15	900	2.1	.9								
18	1,080	3.2	1.4								
20	1,200	3.9	1.7								
25	1,500	5.3	2.3	1.5	.64						
30	1,800	7.6	3.3	2.1	.90						
35	2,100	10.2	4.4	2.8	1.2						
40	2,400	13.2	5.7	3.5	1.5	1.2	.52				
45	2,700	16.2	7.0	4.2	1.8	1.6	.67				
50	3,000	19.4	8.4	5.1	2.2	1.8	.80				
60	3,600	27.7	12.0	6.9	3.0	2.5	1.1	1.1	.47		
70	4,200	40.0	16.0	9.2	4.0	3.5	1.5	1.4	.60		
75	4,500	41.6	18.0	9.9	4.3	3.7	1.6	1.6	.70		
80	4,800	45.0	19.5	11.6	5.0	4.2	1.8	1.8	.80		
90	5,400	50.8	22.0	13.9	6.0	4.8	2.1	2.2	.95		
100	6,000			16.9	7.3	6.2	2.7	2.8	1.2		
125	7,500			25.4	11.0	8.6	3.7	3.7	1.6		
150	9,000			32.3	14.0	11.6	5.0	4.8	2.1	1.2	.51
175	10,500			41.6	18.0	16.2	7.0	6.9	3.0	1.7	.75
200	12,000			57.8	25.0	20.8	9.0	9.0	3.9	2.2	.95
250	15,000					32.3	14.0	13.9	6.0	3.5	1.5
300	18,000					41.6	18.0	18.5	8.0	4.6	2.0
350	21,000							32.3	14.0	5.8	2.5
400	24,000							39.3	17.0	7.2	3.1
450	27,000							44.0	19.0	9.2	4.0
500	30,000									11.1	4.8
750	45,000									23.1	10.0
1000	60,000									37.0	16.0

APPENDIX I

Standard Specifications

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM)

ASTM A53/A53M-02	Pipe, Steel, Black and Hot-Dipped, Zinc-Coated, Welded and Seamless
ASTM D1784-99	Rigid Poly(Vinyl Chloride) (PVC) Compounds and Chlorinated Poly(Vinyl Chloride) (CPVC) Compounds
ASTM D1785-99	Poly(Vinyl Chloride) (PVC) Plastic Pipe, Schedules 40, 80, and 120
ASTM D2241-00	Poly(Vinyl Chloride) (PVC) Pressure-Rated Pipe (SDR Series)
ASTM D2464-99	Threaded Poly(Vinyl Chloride) (PVC) Plastic Pipe Fittings, Schedule 80
ASTM D2466-02	Poly(Vinyl Chloride) (PVC) Plastic Pipe Fittings, Schedule 40
ASTM D2467-02	Poly(Vinyl Chloride) (PVC) Plastic Pipe Fittings, Schedule 80
ASTM D2564-02	Solvent Cements for Poly(Vinyl Chloride) (PVC) Plastic Piping Systems
ASTM D2657-97	Heat Fusion Joining Polyolefin Pipe and Fittings
ASTM D2855-96	Making Solvent-Cemented Joints with Poly(Vinyl Chloride) (PVC) Pipe and Fittings
ASTM F477-02	Elastomeric Seals (Gaskets) for Joining Plastic Pipe

ASME INTERNATIONAL (ASME)

ASME B1.20.1-1983	Pipe Threads, General Purpose, Inch
ASME B16.3-1998	Malleable Iron Threaded Fittings 98’

AMERICAN WATER WORKS ASSOCIATION (AWWA)

AWWA B300-99	Hypochlorites
AWWA B301-99	Liquid Chlorine
AWWA C104/A21.4-95	Cement-Mortar Lining for Ductile-Iron Pipe and Fittings for Water
AWWA C110/A21.10-98	Ductile-Iron and Gray-Iron Fittings, 3 In.-48 In. (76 mm-1,219 mm), for Water
AWWA C111/A21.11-00	Rubber-Gasket Joints for Ductile-Iron Pressure Pipe and Fittings
AWWA C115/A21.15-99	Flanged Ductile-Iron Pipe with Ductile-Iron or Gray-Iron Threaded Flanges
AWWA C151/A21.51-02	Ductile-Iron Pipe, Centrifugally Cast, for Water
AWWA C153/A21.53-00	Ductile-Iron Compact Fittings for Water Service
AWWA C207-01	Steel Pipe Flanges for Waterworks Service - Sizes 4 In. Through 144 In. (100 mm Through 3,600 mm)
AWWA C500-93	Metal-Sealed Gate Valves for Water Supply Service

AWWA C600-99	Installation of Ductile-Iron Water Mains and Their Appurtenances
AWWA C606-97	Grooved and Shouldered Joints
AWWA C651-99	Disinfecting Water Mains
AWWA C900-97	Polyvinyl Chloride (PVC) Pressure Pipe, and Fabricated Fittings, 4 In.-12 In. (100 mm-300 mm), for Water Dist.
AWWA C901-96	Polyethylene (PE) Pressure Pipe and Tubing, 1/2 In. (13 mm) Through 3 In. (76 mm), for Water Service
AWWA M23	Manual M23 *PVC Pipe - Design and Installation*

MANUFACTURERS STANDARDIZATION SOCIETY OF THE VALVE AND FITTINGS INDUSTRY (MSS)

MSS SP-80-1997	Bronze Gate, Globe, Angle and Check Valve