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UNDERSTANDING WATER SUPPLY AND TREATMENT FOR INDIVIDUAL AND SMALL COMMUNITY SYSTEMS

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Understanding Water Supply & Treatment for Individual & Small Community Systems

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PREFACE

This paper is one of a series published by Volunteers in Technical Assistance to provide an introduction to specific state-of-the-art technologies of interest to people in developing countries. The papers are intended to be used as guidelines to help people choose technologies that are suitable to their situations. They are not intended to provide construction or implementation details. People are urged to contact VITA or a similar organization for further information and technical assistance if they find that a particular technology seems to meet their needs.

The papers in the series were written, reviewed, and illustrated almost entirely by VITA Volunteer technical experts on a purely voluntary basis. Some 500 volunteers were involved in the production of the first 100 titles issued, contributing approximately 5,000 hours of their time. VITA staff included Maria Giannuzzi as editor, Suzanne Brooks handling typesetting and layout, and Margaret Crouch as project manager.

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VITA is a private, nonprofit organization that supports people working on technical problems in developing countries. VITA offers information and assistance aimed at helping individuals and groups to select and implement technologies appropriate to their situations. VITA maintains an international Inquiry Service, a specialized documentation center, and a computerized roster of volunteer technical consultants; manages long-term field projects; and publishes a variety of technical manuals and papers.

UNDERSTANDING WATER SUPPLY AND TREATMENT FOR INDIVIDUAL AND SMALL COMMUNITY SYSTEMS

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I. INTRODUCTION

The design, construction, and operation of small-scale water treatment systems for individual homes and small communities represent a significant challenge to public health because of the wide variety of water quality conditions in developing countries. Because developing countries often lack expertise for designing and operating such systems, these systems are often developed under extreme limitations of both materials and personnel. For this reason, any system considered for individual homes or small communities in developing countries must achieve the basic goals of water purification through simple design, operation, and maintenance.

For water to be considered suitable for drinking, it should be aesthetically pleasing; that is, it should look, smell, and taste good. It must also be wholesome; that is, it should not contain any substances that cause sickness or disease (pathogens). These two characteristics are mutually important in that water must be "acceptable" to consumers before they will use it, and free of harmful agents if it is to be used safely. It is not uncommon for consumers to select water that is aesthetically pleasing but of questionable wholesomeness, over less aesthetically pleasing water that is free of disease agents. Consumers tend to judge the quality of water by the way it looks and tastes, rather than also taking into account the wholesomeness of the water.

The ideal small-scale water treatment system would be affordable, simple to design, construct, and operate; and capable of changing unacceptable water to water that is free of taste, odor, turbidity (cloudiness or discoloration), and disease agents in a single process. Another desirable feature would be for the system to stop operating automatically if it is producing water that is not fit for consumption; that is, it should operate only if it is operating properly. In reality, however, there is no perfect system. Nevertheless, in developing a system, the designer should always strive to achieve adequate quantity in the least technically complicated way.

This paper provides guidelines on how to choose a water source, and how to purify and retrieve water to ensure that it is safe for human consumption. Applications are general in nature, relying on the creativity of the system designer to draw from whatever resources are available to develop a water treatment system capable of improving the water supply.

II. BASIC THEORY OF WATER SUPPLY

THE HYDROLOGIC CYCLE

The hydrologic cycle (water cycle) traces the path of water from the oceans to the atmosphere, rivers, ground, swamps, and eventually back to the oceans (Figure 1). As the water progresses

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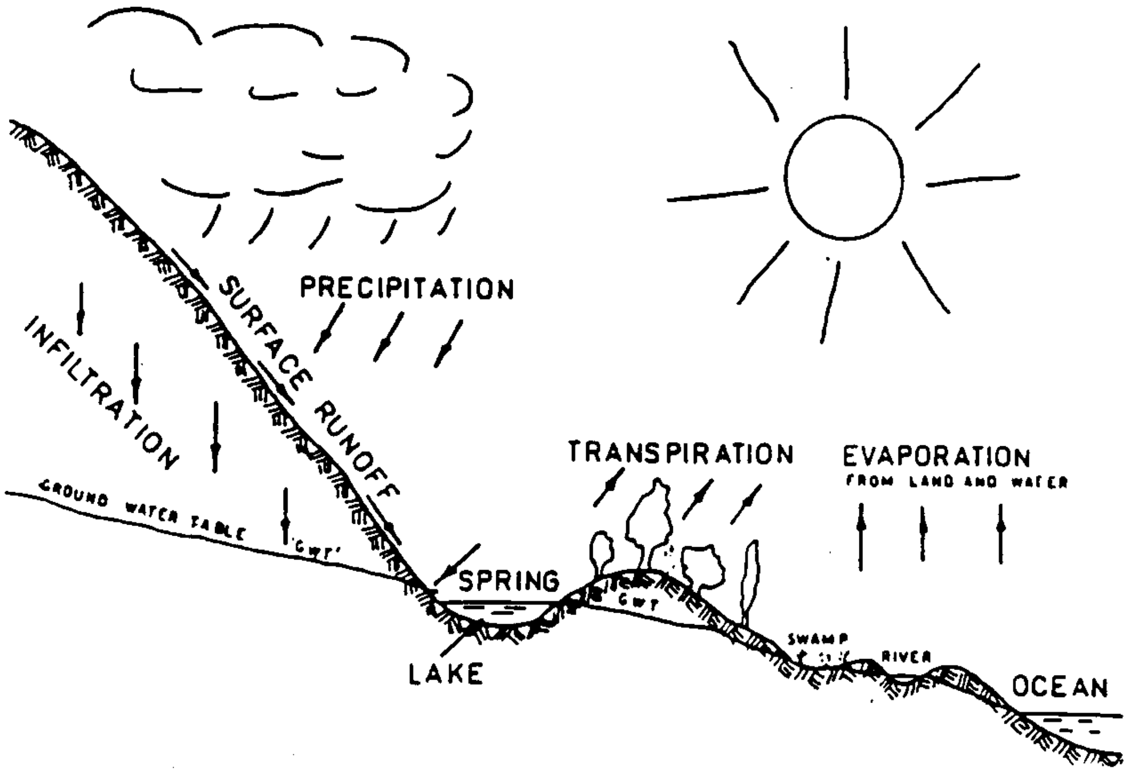

Figure 1. Hydrologic Cycle

Source: Swiss Association for Technical Assistance, ed., Manual for Rural Water Supply (Zurich: Swiss Center for Appropriate Technology, 1980), p. 5.

through the various stages of the hydrologic cycle, it is affected by many factors that determine its ultimate quality. The water can be extracted for use at any stage in the cycle; however, the

quantity and quality of water available often limits the user to only a few choices. For drinking water, it is important to select a water source that provides an adequate supply of water of the highest quality possible.

SOURCES OF WATER

Precipitation

In areas where air pollution is not a major factor, rain water can provide a suitable, high-quality source of water. Typically, rain is collected from rooftops through gutters and stored in tanks or cisterns (underground storage vessels). Because the roof (or any collection surface) is subject to contamination from nesting and flying birds and airborne dust, one cannot assume that this source of water is suitable for consumption. Underground storage chambers are subject to infiltration as well as leakage. Problems with infiltration can be serious, as water from nearby outdoor toilets and subsurface sewage disposal systems can enter the cistern when the water level in the cistern is low. For these reasons, rain water must always be disinfected before it is consumed. Periodic inspection of the cistern is recommended, with annual cleaning to remove any sediment that has accumulated.

The cistern should be sized to provide an adequate supply of water throughout low rainfall seasons. In many situations, this will limit the feasibility of using rain water as a year-round source of water. The amount of water available is easily

calculated by multiplying the annual or seasonal average rainfall (in meters) by the surface area of the collecting surface (in square meters). Provisions for screening out large particles (leaves) and keeping out small animals should be included in any storage system.

Springs

A spring represents a point in the hydrologic cycle where ground water meets the land surface and flows into a stream. The water quality at the point of surfacing is often excellent, as the water has usually traveled, or percolated, through thick layers of soil. In this process of percolation, the water picks up dissolved minerals (calcium, magnesium, iron, etc.) and is purified of biological pathogens (disease producing organisms). The spring will exhibit varying quantity and quality depending on the geologic formation in the area. A continuously flowing spring that is always clear can provide a good source of drinking water.

In selecting springs as a source of supply, particular caution should be used in areas of what is called Karst (limestone) topography. These areas typically contain many sinkholes, or depressions, through which surface drainage is transported to the ground water (Figure 2). Water entering the ground water by this

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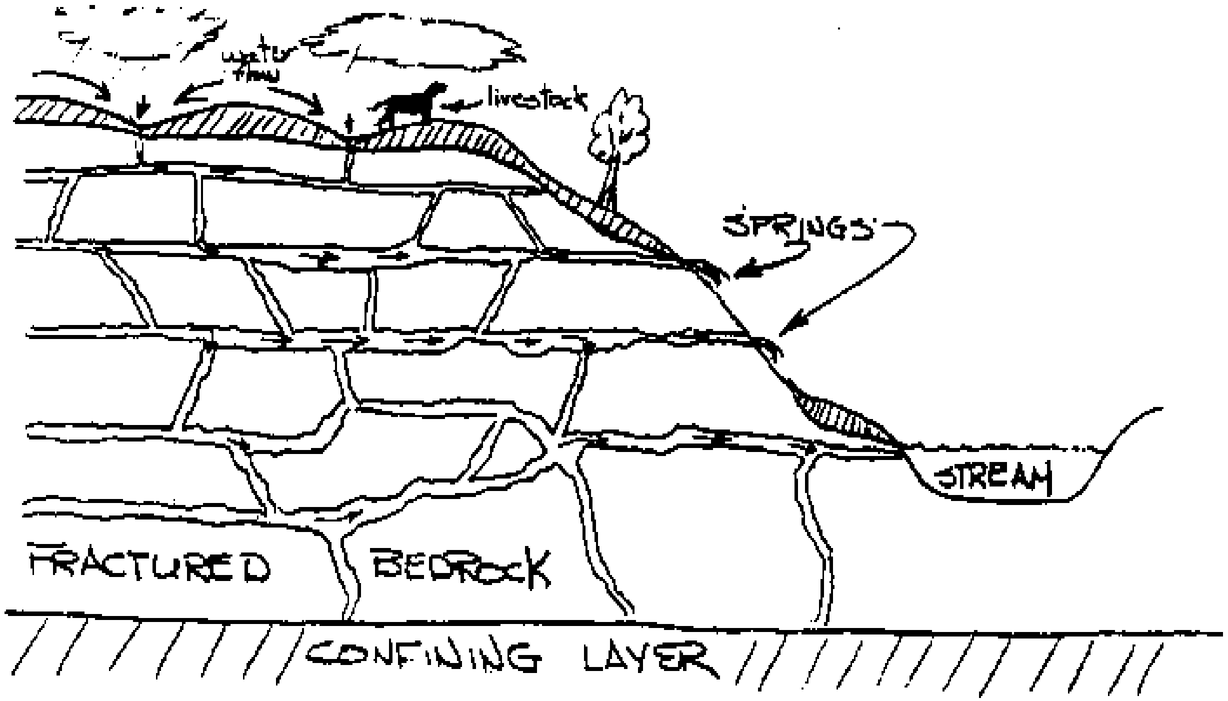

Figure 2. Typical Hydraulic System for a Stream Located in a Karst Geologic Formation

path bypasses the percolation process that purifies it. As a result, springs in these areas can produce poor-quality water much like surface water, and must be treated appropriately.

Ground Water

If a stream is located in a sand and gravel stratum, a supply of suitable drinking water might be obtained easily by drilling or digging a well into the aquifer that feeds the river (Figure 3).

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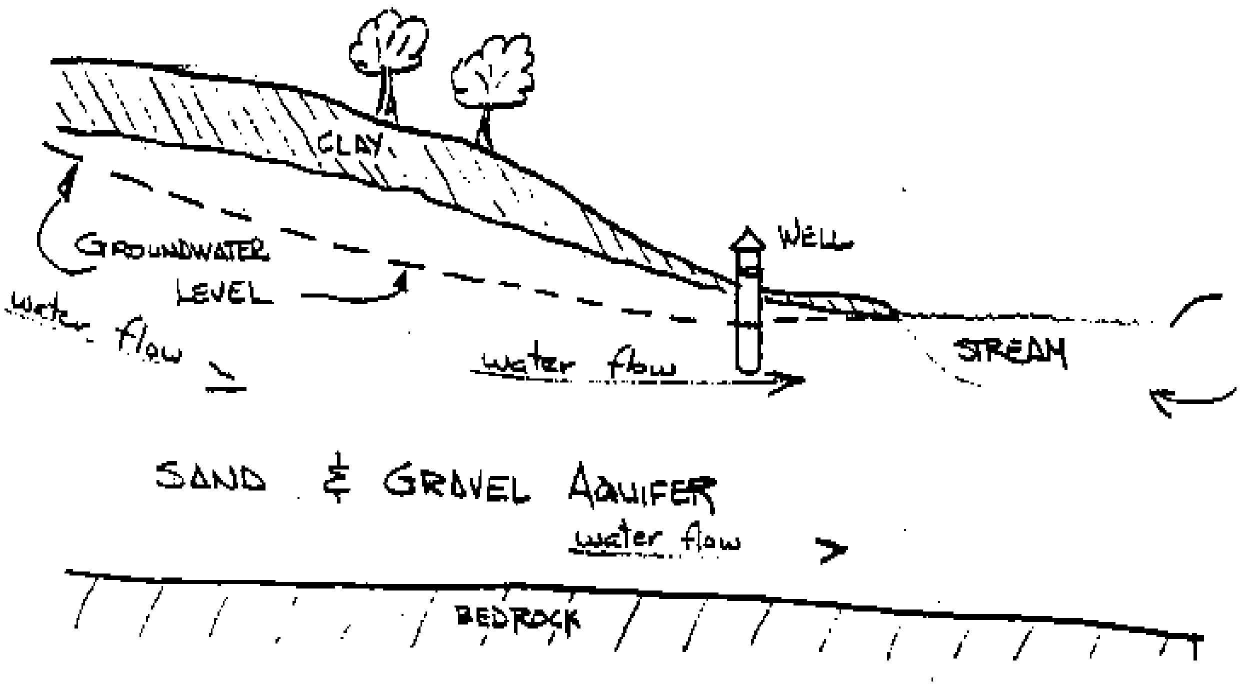

Figure 3. Typical Hydraulic System for a Stream Located Over a Sand and Gravel Aquifer

Since surface streams typically define the lowest hydraulic gradient in an area, a well dug into the sand and gravel will typically draw water from highland areas; if these areas have not

undergone extensive development or become contaminated (such as by dumps and landfills), they will usually provide sanitary water. As with spring water, ground water from limestone strata must be suspect quality. Depending on local geological conditions, however, the water may contain unacceptably high levels of iron, manganese, and/or salt, making it unpalatable.

Ground water can be extracted from any point in the geologic formation, but the depth and type of cover over the ground water will determine the feasibility of constructing a well for water supply. Water from a well typically exhibits a constant quality. When the well is properly constructed to eliminate surface contamination, it can provide an excellent source of drinking water.

Surface Streams

Villages are typically established near a source of water and transportation routes, as these two factors often determine their habitability and reason for existence. The source of water for villages is typically surface water. Surface water can be used to supply water for drinking and washing; it can be a means of transportation; it can be used for irrigation, livestock watering, or for sewage disposal. These multiple uses are often conflicting, and the water source may not be able to meet all the demands placed upon it.

While surface streams, rivers, and lakes often represent the most accessible supply of water to a village, they are also the most vulnerable to contamination. Surface water typically has highly

variable water quality, and can be the source of many diseases. To be suitable for consumption, surface water must always be treated to remove harmful substances.

WATER SOURCE SELECTION

For either surface water supply or ground water supply, the point of water withdrawal should be made as far upstream as possible. Two principal drawbacks to this concept are (1) people living below the water source must travel greater distances to obtain their water; and (2) the higher the source of water, the less volume of water there is. A basic understanding of the topography and geology of the area can help in locating the best point of water withdrawal.

In selecting a source of water, attention should be given to the use of land in the immediate watershed and the chance of contamination to the source. Problems with unreliable water quality can be largely eliminated or reduced by avoiding areas that will likely be contaminated by human waste water, agricultural/livestock runoff, and industrial discharge. The most important step in developing a potable water supply is the selection of the QRhighest-quality water source possible.

It is difficult to define categorically a particular source of water as superior to another. However, ground water supplies and rain water do have a greater chance of being free of serious contamination than do surface water supplies. Of the surface supplies, springs that provide clear water under all conditions

and that are located in areas that do not have numerous sinkholes are preferred over surface streams. Any surface water, including clear-running mountain streams, can be contaminated by pathogens and must be treated before use. No matter what source of water is being considered, the local factors influencing the water quality must always be evaluated. If possible, one should call upon the local health authorities to analyze the suitability of a particular water source.

WATER EXTRACTION AND TRANSPORT

There are many ways of extracting and transporting water from a source to the point of use. Water can be taken from streams and wells by hand and transported in buckets or ceramic vessels. Where materials and technology are available, water can be pumped by electric, diesel, or wind-powered pumps and transported through pipelines. In situations where the source is located at an altitude higher than the point of use, the water can be transported by gravity. A detailed discussion of these techniques exceeds the scope of this paper; to obtain this information, readers are directed to other VITA publications.

Caution should be used in determining how the water will be extracted and transported. Extreme care should be exercised to avoid contamination of the water. Whenever possible, hand powered or machine-powered pumps should be installed, and the use of buckets, which can contaminate the source, avoided. Pumps also allow a well to be sealed, eliminating the possibility of foreign objects or contaminated surface water getting into the well.

WATER TREATMENT

This section discusses relatively simple, reliable, and efficient methods of treating water to remove solids and pathogens. Methods for the removal of additional toxic compounds (e.g., heavy metals, industrial solvents, pesticides) are beyond the scope of this paper and are not covered here.

Water treatment for any fresh-water system basically involves the removal of solids, the removal of pathogens (disease-causing bacteria, viruses, and other microbials), and the removal of substances that impart bad tastes and odors. In isolated instances, additional toxic compounds must be removed before the water can be drunk. In supplying water to individual homes and villages in rural areas, it is therefore far more desirable to locate a water source free of such toxic agents, because the removal of such agents can be technically difficult and economically burdensome.

Solids in water may be of no health concern in themselves. However, solids (clay, organic material, etc.) in water can protect pathogens from disinfection, and result in water quality problems even in treated systems. Turbid drinking water is not particularly appealing, which may lead consumers to select an alternate source of clear water. In doing so, however, unknowing consumers could end up drinking water that is not wholesome, even though it appears to be of higher quality. Thus, one goal in the treatment of water should be the removal of suspended solids.

Solids in water can be divided into three categories: those that float, those that sink, and those that are suspended (that is, they neither float nor sink within reasonable periods of time). Of these three categories, the suspended solids are the most difficult to remove. Floating solids can be avoided by drawing water from below the surface of the water source. Solids that settle without chemical treatment can often be removed by allowing the water to remain for one day or more in a facility designed for quiescent conditions (low water velocities). Suspended solids, however, must be removed by either chemical or physical treatment methods. To remove them in this way involves more sophisticated equipment and a higher level of maintenance.

Sedimentation

Sedimentation; or removal of those solids that sink, was commonly the only treatment provided to turbid streams through the 1800s. This process relies on the rate at which the material in the water settles or sinks, and the retention of water in such a manner as to allow the material to reach the bottom of the basin. In sedimentation basins, it is important to remember that the principal design variable is the surface area of the basin, not the overall volume. The basin need only be deep enough to ensure good hydraulic flow patterns. Proper design of inlet and outlet structures is necessary to prevent the system from short-circuiting, and to avoid the removal of deposits from the floor of the basin.

Sedimentation rates for solids can vary from 10 meters/hour for heavy silts to less than 0.005 meters/hour (5 mm/hour) for fine clays. Thus, the composition of the solids in the water will determine the feasibility and design criteria for the sedimentation process. Fine clay suspensions and water with high color content can be treated chemically to make the particles settle more readily. Such treatment, called chemical coagulation, requires the availability of chemicals, chemical feed equipment, and routine sludge removal for proper operation. Aluminum and iron salts (alum, ferric sulfate) are typically used when available, along with organic polymers. Maintaining these processes is expensive and requires trained personnel. Thus, chemical coagulation is not typically considered for individual/village water supplies.

A sedimentation basin can be made of any suitable material. It can be as simple as a clay pot or as complicated as a concrete basin with continuous sludge drawoff. Consideration should be given to the amount of solids that will be collected in the basin, and the methods of solids removal that will be used. If the solids are to be removed in a batch operation (requiring the temporary halting of the operation), additional units will be necessary if a continuous supply of water is required. In general, the additional units should be provided if possible, although this can cause an increase in overall construction costs.

The dimensions of a particular basin are determined by the particles to be settled, land constraints, the need for long-term

storage, and other physical and economic conditions. Technical assistance in designing the facility should be sought whenever available.

Storing water for extended periods of time can result in the destruction of bacteria, as well as turbidity removal. Storage for two weeks or longer can remove up to 90 percent of disease-causing organisms. This process, however, is not effective for removing all pathogenics, and fine turbidity will remain in suspension. In addition, algae may grow in the water during this time, making the water taste and smell bad. In general, water storage is a beneficial pretreatment if algae growth is not a problem. Caution must be taken so far as possible to prevent the contamination of the storage area by human and animal wastes.

Filtration

Filtration has long been recognized as an effective method of water purification. The ancient Egyptians recognized that boiling and filtering (among other less proven techniques) were capable of rendering foul water suitable for drinking. Prior to 1700, it was commonly believed that filtration could remove salt from sea water. In the 18th and 19th centuries, many patents were issued in France and England for various filtration devices, both small units for in-house use and larger filters for municipalities. These filters used sand, cinders, charcoal, sponge, wool, and many other materials. The earliest mention of the mode of action in slow sand filters was in the 1840s when an Englishman noted in a chemistry text that the filter media served to support "finer materials of mud or precipitate...which...form the bed that really filters water." This citation recognizes the importance of the formation of a filtering layer that must be allowed to develop on top of the sand before the filter can operate efficiently.

Slow sand filters (so named because of the relatively slow downward speed or velocity maintained in the filters) have been noted as being effective for solids removal and bacterial reduction for over two centuries. These early filters were not effective for highly turbid streams, however, because of the short filter runs experienced before clogging. The processes of chemical coagulation and sedimentation paved the way for the development of rapid sand filters, which became popular in the early 1900s. A few modern treatment plants still use slow sand filtration, although the standard for most large utilities is chemical coagulation, sedimentation (although direct filtration is becoming increasingly popular), and rapid filtration through mixed media.

This paper is limited to slow sand filtration only, because it requires simple operating conditions and generally produces high-quality water. Adequate units range from sand-filled drums or earthen-lined basins to concrete structures with complex under-drain systems. Each type of unit suits a particular situation.

A simple filter, designed for domestic use, can be made from a 55-gallon drum and sand. It can improve the quality of surface water significantly, as long as initial turbidities are not too high. As with any slow filter, the surface of the filter must be

kept wet to maintain the biological growth known as the "schmutzdecke." (The schmutzdecke consists of a variety of biologically active microorganisms that break down organic matter, while much of the suspended inorganic matter is retained by straining). This type of filter can produce 10 to 20 liters of water per hour if operated continuously, but intermittent operation is more typical. In such an operation, the flow rate through the filter should be limited so as not to exceed optimum rates (10 to 20 liters per hour). The filter should be kept covered to eliminate algae growth and contamination from dust. For proper filtration, the surface of the filter should always be kept submerged.

The selection of materials for the construction of a domestic filter will depend mainly on what resources are available. If a 55-gallon drum is selected, the interior of the drum must be protected against rusting. Containers that have been used for storing pesticides, herbicides, and other toxic chemicals must not be used. The preferred filter medium is sand with an effective size in the range of 0.15 to 0.35 mm. Ungraded river sand is acceptable if nothing else is available. The sand should be thoroughly washed by panning to remove very fine sand, clays, and organic matter. The sand should be placed in the container in a layer about 1 meter deep, and arranged with inlet-outlet piping to allow easy operation. A typical slow sand filter is shown in Figure 4.

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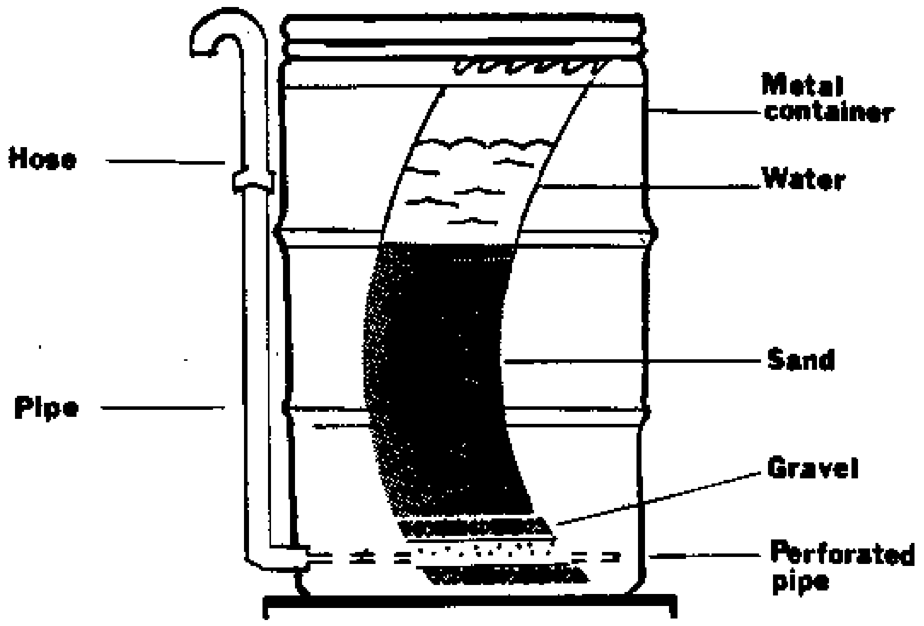

Figure 4. Basic Elements of a Slow Sand Filter

The design and operation of a slow sand filter for a small village should be supervised by a qualified person. The design criteria should take into account available materials and funds, as well as the suitability of the water source for filtration.

Regardless of the efficiency of a sand filter for removing turbidity and reducing bacteria, sand filters alone should not be considered adequate for the treatment of contaminated surface waters. In every case, some form of disinfection should also be used if the water is to be used for human consumption.

Disinfection

Although sedimentation and filtration can greatly reduce the amount of bacteria in contaminated water, the reliability of these two processes to produce water suitable for drinking is limited. Many pathogens can survive even after these processes are operated properly. Removal of pathogens can be almost negligible when the processes are carried out improperly. It is necessary that any water from a contaminated source be disinfected before consumption, if at all possible.

Disinfection can be accomplished by mechanical, chemical, and thermal techniques. (Other techniques, such as radiation, are beyond the scope of this paper.) If the water is sufficiently free of suspended solids, it can be passed through a small-pore filter, which is capable of physically blocking the path of microorganisms. Certain stone filters have this capability, but the filtering rate is relatively slow. Chemical agents, particularly the halogens (chlorine, bromine, iodine), have been demonstrated to be highly efficient in killing bacteria. A universally recognized method for killing bacteria is boiling, which can destroy life forms in even turbid suspensions. Each method of disinfection has its limitations, which should be recognized before the technology is adopted.

A recent evaluation of ceramic filters which are capable of meeting WHO standards for bacterial quality indicated that of all the strainers tested, only carved stone filters were capable of yielding acceptable bacterial quality by straining alone. Other filters, impregnated with silver, were effective, but the mode of disinfection was not limited to straining alone. The carved stone filter was effective, but it was also relatively heavy and expensive. It should be noted that filters that strain out the test organisms (coliform bacteria) do not necessarily also remove the pathogenic viruses, which are typically much smaller than bacteria. One should be cautious, therefore, in interpreting the results of straining for pathogen removal based upon indicator organisms.

The ability of filtration and straining to remove large numbers of pathogens should be emphasized. Properly filtered water is considered to be far more healthful than unfiltered water. However, the complete removal of pathogens cannot be guaranteed.
For this reason, water must undergo further disinfection through chlorination or boiling. These two disinfection methods are discussed in the sections that follow.

Chlorination

Chemical agents such as chlorine, bromine, and iodine have been used to eliminate waterborne diseases in major water supplies since the early 1900s. The most universally supplied agent is chlorine. Chlorine combines with water to form hypochlorous acid, a highly efficient bacteriocide. The amount of hypochlorous acid

formed by a dose of a chlorine compound will depend on the amount of organic material and ammonia present, and the pH of the water. Typical chlorine amounts in the range of 1.0 mg/1 will provide adequate protection for fairly clear water; however, suspended solids can protect pathogens from the disinfectant and result in incomplete disinfection. Thus, any water that is disinfected by chlorine should be free of high levels of suspended solids.

One of the major advantages of the halogen disinfectants is their ability to form stable residuals, which continue to protect the water from recontamination. Depending on the quality of the water, the residual can persist for as long as a week in the absence of light. (The chlorine residual is quickly reduced in the presence of sunlight.) One major disadvantage of the residual, however, is the possibility that the water will develop a medicinal or chlorinous taste and odor. The foul taste and odor are usually not caused by the chlorine (or any other halogen), but by compounds that have formed with the chlorine. A common contaminant, phenol, yields a strong, distinct odor that is detectable at very low levels. In certain situations, chlorinous odors can be removed by increasing the chlorine dosage, which oxidizes the odor-causing compounds. In the absence of a sophisticated laboratory, the suitable amount of chemicals needed for this purpose can be determined by trial and error. Table 1 provides instructions for chlorinating drinking water.

Many techniques are available for putting the chemicals into water, ranging from a single dose into a container to a continuous feed from some type of storage vessel. In considering a technique for small-scale use, the reliability and ease of use should be given very high regard. Any technique that is not used correctly could yield a false sense of security that could be quite dangerous.

Boiling

Boiling is perhaps the most well-known and universally applied method of disinfection. The common consumption of boiled drinks (teas) was undoubtedly fostered by the realization that these drinks were "healthful" (or, more appropriately, non-pathogenic).

Boiling water--even turbid water--for three to five minutes effectively destroys all pathogens. However, boiled water often tastes "flat." This flat taste can be remedied by allowing the water to stand for one or more days while exposing it to the air. Typically, 1 kilogram of wood is required to boil about 1 liter of water.

Caution should be exercised in storing boiled water, as the potential for recontamination is quite high. The water should be stored in a closed, dark container, preferably in a cool location. As with any stored water, care should be taken to avoid contaminating the water when taking water out of the container.

III. SUMMARY

In developing a treatment system for a small water supply, emphasis should be placed first on securing the highest quality of water possible (e.g., rain water, ground water, surface water). Beyond this, any treatment technique that is readily available, affordable, simple to maintain and operate, and capable of improving the quality of the water can be used. In some cases, it may be impossible to provide chlorination due to the unavailability of raw material or the unreliability of operation.

Other forms of treatment, although less efficient than chlorination, may be more reliable and thus provide a consistently better quality of water than would a less reliable treatment technique. The most effective treatment technique is one that will not yield water if it is not operating properly. To some extent, filtration systems meet this criterion and thus are very attractive as a reliable, small-scale form of treatment. Additional disinfection is always desirable, however, to ensure pathogen-free drinking water.

Table 1. Amounts of Chemicals Needed to Disinfect Water for Drinking [a]

Water (m3)	Bleaching Powder (25-35%) (g)	High Strength Cal-Hypochl (70%) (g)	Liquid Bleach (52% sodium hypochlorite) (ml)
1	2.3	1	14
1.2	3	1.2	17
1.5	3.5	1.5	21
2	5	2	28

2.5	6	2.5	35
3	7	3	42
4	9	4	56
5	12	5	70
6	14	6	84
7	16	7	98
8	19	8	110
10	23	10	140
12	28	12	170
15	35	15	210
20	50	20	280
30	70	30	420
40	90	40	560
50	120	50	700
60	140	60	840
70	160	70	980
80	190	80	1,100
100	230	100	1,400
120	280	120	1,700
150	350	150	2,100
200	470	200	2,800
250	580	250	3,500
300	700	300	4,200
400	940	400	5,600
500	1,170	500	7,000

[a] Approximate dose = 0.7 mg of applied chlorine per liter of water.

Note: For chlorinating drinking water, follow these instructions: (1) use one of the chemicals listed in the table, and choose the amount according to the quantity of water in the distribution tank, cistern, or tanker; (2) dissolve the chemicals first in a bucket of water (not more than about 100 g of calcium hypochlorite or bleaching powder in one bucket of water), and pour the solution into the tank (if possible, agitate the water to ensure good mixing); and (3) repeat this chlorination procedure as soon as the level of residual chlorine in the water drops below 0.2 mg per liter.

Source: S. Rajagopalan. Guide to Simple Sanitary for the Control of Enteric Diseases, (Geneva, World Health Organization, 1974.)

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