CHAPTER FIVE

DRINKING WATER

Water supply systems vary greatly in size, ranging from small systems serving individual families to systems serving millions of consumers. The surveillance of drinking water quality has been defined as "The continuous and vigilant public health assessment and overview of the safety and acceptability of drinking water supplies." (WHO, 1976) The applications of this definition in rural and urban areas are very different and will be discussed in separate sections of this chapter. The first section, Assessment of Urban Water Supply, reflects many of the recommendations of the World Health Organization for survillance procedures applicable to developing countries. (WHO, Surveillance of Drinking-Water Quality Geneva: World Health Organization Monograph Series No. 63, 1976.)

Assessment of Urban Water Supply

The elements of a surveillance program include careful and critical examination of the following:

- quality of source
- output of source
- protection of source
- adequacy and reliability of treatment (if any)
- distribution system (quality, pressure, and continuity) (if any)
- quality control (records, sampling, tests)
- cross-connection and back-siphonage control (if any)
- chlorine residual in the distribution system (where appropriate) (if any)
- construction and repair practices (including disinfection before services are resumed)
- maintenance procedures
- standard of operation

Necessary surveillance programs differ as a function of level of economic development, government priorities, personnel capabilities, natural resources, water needs and uses, fiscal capability, etc. Pragmatic surveillance programs should be planned to adapt to local existing situations and economic resources. Once such programs are implemented and consolidated, plans to develop by stages to the ultimately desired level of treatment, distribution, and surveillance should be made.

Surveillance

In choosing the systems to be included in a routine surveillance program, the practice of one health agency may be used as an illustration. This agency, in a state with a population of about 5.5 million, has defined a community water supply as "any system, publicly or privately owned, which provides water intended for drinking to 25 or more persons." Over a period of several years the agency has identified and listed some 3000 such systems and it inspects each system periodically. The agency is now planning to redefine community water supply systems as "those systems serving 10 or more consumers," and is expanding its staff and laboratories to supervise an additional 1000 systems.

What is worth noting is not the number of consumers specified in the definition, whether 10, 25, 100, or 1000, but, rather, the selection of an interim number, which represent a realistic interim goal, and the stepwise movement, with development of staff and laboratory capacity, to a more stringent definition of a community water supply system.

Essential to these decisions is the availability of an inventory or list of water supply systems. The number and size distribution of the small systems must in general be estimates. Only when staff resources become available to search for small systems in the field will many of them be identified. In addition to water systems serving resident populations, systems for restaurants, hotels, parks, sea ports, airports, railway stations, fairs, centers of pilgrimage, festivals, military camps, and other concentrations of transient populations should receive particular attention because of their potential role in widespread disease transmission.

In carrying out a survey of water systems, other highly useful information can be gathered at marginal cost. In cities this includes such data as water consumption (where records exist), water sources, laboratories, future needs, and planned expansions.

For the purposes of assessment of surveillance activities the following should be investigated: (1) survey procedure and purpose, (2) timing and frequency, (3) qualifications of personnel.

The sanitary survey is an on-site inspection and evaluation by a qualified person of all conditions, devices, and practices in the water supply system that pose, or could pose, a danger to the health and well being of the consumer. Sanitary surveys may include the entire water supply system or they may be confined to source, treatment, or distribution, depending on their purpose.

Printed guidelines, checklists and forms for recording sanitary surveys are of considerable value. Report forms should be drawn up in the national language, mimeographed and used on a regular basis. In addition to their educational value as checklists, such forms become part of a permanent record and are useful for enforcement of quality standards and follow up evaluations of connections made. (An example of a sanitary survey reporting form is presented in Annex A.)

Sanitary surveys should be undertaken both on a regular basis and also under special conditions. The comprehensiveness of the survey and the necessary qualifications of the surveyor are determined largely by the significance of the particular survey.

The most important survey is that undertaken when new sources of water are being developed. This survey should be made in sufficient detail to determine (1) the suitability of the source, and (2) the amount of treatment required before the raw water can be considered suitable for human consumption. When alternative water sources are under consideration each should be surveyed. Physical, bacteriological, and chemical analyses should be carried out during surveys to find major new surface water supplies. Requirements for chemical and bacteriological analyses of raw water sources will depend on the resources available. The guiding principle is that no new public water supply should be approved without a sanitary survey made, or accepted, by an agency with surveillance responsibility.

Another important and urgent survey is that undertaken when laboratory analysis or complaints from consumers indicate the possibility of contamination. A survey should be started immediately to identify the source of possible contamination. Attention should be given first to the most common causes of contamination. In systems using chlorination treatment, residual chlorine levels should be checked immediately and chlorination equipment and records examined.

Even more urgent is a sanitary survey when epidemiological evidence indicates an outbreak of water-borne disease in or near the area served by the water supply system. This should be undertaken even though laboratory records indicate water is of a satisfactory quality. Contamination of water supplies is often sporadic and undetected by intermittent sampling. In addition there are always the possibilities of errors in sampling or laboratory procedure. During epidemics the sanitary survey should not be limited to the piped public water supply but should be extended to all water sources in the community.

A sanitary survey should be made when any significant change or event occurs that could affect water quality; for example, the beginning of the rainy season, new industrial construction work on a watershed, an outbreak of typhoid or cholera in a nearby area or country, or serious complaints by consumers.

Personnel

The professional judgment and competence of the survey officer ultimately determine the reliability of the data and information collected. Qualified persons should therefore conduct the sanitary surveys. Ideally, the sanitary surveyor should combine an understanding of water supply technology and the principles of public health with experience in water supply operations and management. At least the national, state, and provincial program directors should possess these qualifications and should have received formal training in sanitary engineering or sanitary science.

The lack of adequate numbers of qualified personnel should be seen not as an excuse for inaction, but as a challenge to establish appropriate training programs. Technical assistance and fellowships are available through WHO and other international bodies.

The performance of the sanitary surveyor should be monitored through occasional spot checks by supervisors. Also, many agencies find that rotation of assignments among the sanitary personnel helps to prevent complacency or worse faults due to overfamiliarity with particular waterworks or their personnel. In smaller water supply systems, additional operator training may be required through short courses or certification programs. A senior waterworks official could accompany the sanitary survey officer during his inspection, not only to remedy any defects uncovered but also because the survey should be considered as a training session.

For all systems, regardless of size, a person must be designated to be responsible for the operation of the system; this person, or his deputy, must be available ("on call") at all times when a system using surface water sources and disinfection procedures is in operation. The principal operators of systems employing chlorination must have on hand devices or equipment for measuring residual chlorine and be competent in their use and in making indicated adjustments to chlorine dosing rates.

Common Surveillance Problems

The World Health Organization (1976) recently engaged in a multi-country survey of common surveillance failures. Many of these reflected lack of capital and humam resources, but some were compounded by complacency and apathy on the part of water supply and surveillance authorities. The reported common failures are presented below for the purposes of assessing effective surveillance:

- Failure to assure general awareness of the danger of outbreaks of water-borne disease and/or to bring such outbreaks to the attention of water purveyors.
- Lack of established surveillance policies and procedures.
- Failure to make sanitary surveys.
- Failure to collect samples of raw and delivered water.
- Failure to enforce correction of deficiencies and remedial measures.
- Failure of laboratories to notify waterworks of results of analyses.
- Inadequate approval program for new sources.
- Failure to adopt and enforce drinking-water standards.
- Failure to protect watershed, wells, and springs from surface contamination.
- Failure to maintain positive continuous hydraulic pressure throughout the distribution system.
- Failure to maintain a continuous chlorine residual in distribution systems.
- Inadequate or non-existent cross-connection and back-siphonage control programs.
- Lack of standard laboratory procedures.
- Failure to maintain plant records, e.g., residual chlorine levels.
- Failure to maintain surveillance records.
- Bacteriological samples taken from fixed locations unrepresentative of the distribution system.
- Failure to disinfect new construction and repair work.
- Lack of adequate legal authority.
- Inadequate budget and manpower.
- Inadequate numbers of personnel suitably trained and qualified.
- Inadequate laboratory facilities and support.
- Failure to promote adequate maintenance programs.

Sampling

Samples are taken from water systems in order to determine whether the water supply is safe for human consumption, and they must therefore be representative of the water supply as a whole. Assessment of sampling practices includes examination of the following: (1) record keeping, (2) sampling frequency and number, (3) location of sampling points, (4) sample collection procedures, (5) transportation of samples, (6) coordination with the laboratory, (7) analyses of water samples, and (8) laboratory practices and facilities, follow up of reports and the ability to have something corrected in the field.

Sampling frequency for public water supplies has traditionally been based on a monthly minimum determined by the population served, fewer bacteriological samples being required from smaller supplies. This practice recognizes the limited resources generally available for surveillance of smaller water supply systems. Even in developed countries the application of identical per capita surveillance budget provides smaller resources for the smaller systems. However, frequency of sampling should take into account the past frequency of unsatisfactory samples, the quality of raw water treated, the number of raw water sources, the adequacy of treatment and capacity of the treatment plant, risks of contamination at the source and in the distribution system, the size and complexity of the distribution system, the risk of an epidemic starting (at international ports or centers of pilgrimage, for example), and the practice of chlorination.

It might be thought that if chlorination is practiced less sampling will be needed. However, field studies in developing countries indicate that water supplies from naturally protected sources— deep wells, for example— are rarely chlorinated. Rather, chlorination may be practiced in water supply systems where the source or distribution system is, or could be, contaminated and where failure of the chlorination system could result in a serious hazard to the health of the population served. However, in many developing countries chlorine is not available. Constant checking of chlorine residual concentrations, when applicable, and bacterial quality is therefore necessary to ensure that immediate remedial action is taken if water of doubtful quality enters the distribution system.

No universally applicable sampling freauencv can be suggested. Recommendations for sampling (numbers of samples and frequency of sampling) are to be found in International Standards for Drinking Water (see reference section). Suggested maximum intervals between successive samples collected from the distribution system, whether the water has or has not been disinfected, and the minimum number of samples to be examined each month are given in the following table.

The number of samples taken and frequency must be decided based on local conditions. The standards for sampling and criteria adopted for local use should be clearly defined, printed and circulated to appropriate personnel, and attainable by water supply systems of the sizes and types specified.

Maximum Intervals Between Successive Samples of Water Entering the Distribution System and Minimum Number of Samples to be Taken

	Maximum Interval Between Successive Samples	Minimum Number of Samples to be Taken from Whole Distribution System Each Month
Less than 20,000	1 month	1 sample per 5,000 population per month
20,000 - 50,000	2 weeks	1 sample per 5,000 population per month
50,000 - 100,000	4 days	1 sample per 10,000 population per month
More than 100,000	1 day	1 sample per 10,000 population per month

Sampling should be rotated through all parts of the distribution system. A common practice, which may yield misleading results, is to collect samples always from the same point— typically from a laboratory tap in the municipal building, a police station, the residence of a waterworks employee, or a particular restaurant. The majority of samples for bacteriological examination and chlorine residual determinations should be taken in known problem areas, for example, areas with a poor previous record, low pressure zones, areas with a high leakage rate, densely populated areas with inadequate sewerage, open or unprotected service reservoirs, dead-ends on pipelines, and areas on the periphery of the system farthest away from the treatment works.

The assessment of sampling procedures in urban areas should consider that many urban areas use water from several sources, ranging from three to 20 or more; water from each source should be periodically sampled. Sources serving larger populations, surface water sources, sources serving older distribution systems, and sources with known water quality problems should be more frequently sampled. In some cities tank trucks are used to distribute water. Watering stations where the trucks are filled should be periodically sampled and the water distributed from the trucks should be randomly sampled without warning given to the driver/purveyor. Trucks should be periodically cleaned and disinfected with chlorine at the watering station.

The WHO (1976) recommends that the following instructions be known and followed in sampling procedures by sample collectors.

- Identification of a sample with the date it was taken, the location, brief particulars of the source, and any special conditions. Standard forms are useful for this purpose.
- Location of sampling points, as described above. Subprofessional personnel should be specifically instructed about sampling sites.
- The use and purpose of dechlorinating compounds, such as sodium thiosulfate, added to the sampling bottle.
- Measurement of residual chlorine. These tests must be performed immediately when the sample is taken.
- Proper procedures for collecting samples to ensure that they are representative and that, for bacteriological examination, sampling bottles are kept in a sterile condition. "The collection of bacteriological samples is to be regarded as of the character of a surgical operation with the observance of similar aseptic precautions, and it should be carried out only by those who have been competently instructed." Where samples are repeatedly contaminated by collectors, a complacent attitude may develop with regard to samples positive for coliform bacteria.
- Proper transportation and storage of samples. Laboratory examination should be started within 24 hours of sampling. In hot climates, samples should if possible be kept cool and protected from exposure to heat or sunlight.

Numerous authoritative, detailed and comprehensive treatises on the physical, chemical, bacteriological, biological, and radiological examination of drinking-waters are readily available. There are also many excellent textbooks dealing with water analysis. However, two particular parameters or measures of quality are so vital to water quality surveillance as to warrant special attention; residual chlorine concentration, and number of coliform bacteria, which gives an index of possible contamination of the water by faecal matter. Residual chlorine concentration can be used as an indication of the ability of the treated nonturbid water to overcome bacterial contamination.

Where chlorine is added to the water the chlorine residual test is, under certain conditions, a useful method for operational quality control. The test is readily learned, quickly and easily performed, inexpensive, and provides an immediate warning of inadequately safeguarded water. The presence of a chlorine residual of adequate concentration for a sufficient length of time provides reasonable assurance that the water is rendered free from pathogenic bacteria. Table 4 shows the residual chlorine concentrations necessary for effective disinfection. Two analytical tests for chlorine residuals are the ortho-tolidine/arsenite test (OTA), and the DPD method (N-diethyl-para-phenylenediamine). The OTA is most commonly used.

If chlorine residual testing is in use, when a residual concentration of less than the allowable minimum is measured at a sampling point, another sample should be taken immediately and the chlorine residual concentration measured. If this sample also proves unsatisfactory for residual chlorine the dosage of chlorine added to the water supply should be increased, the line flushed, and sampling continued until a satisfactory chlorine residual concentration is attained. If increasing the chlorine dosage is ineffective, or if excessive chlorination is required, a sanitary survey for potential contamination of the supply should be made at once by water supply personnel. If necessary, pipelines and storage reservoirs adjacent to the sampling point should be flushed, cleaned, and disinfected. In addition, waterworks having the laboratory capability should obtain a water sample for bacteriological examination. Should these measures prove inadequate, the surveillance agency should be asked for assistance and potentially affected consumers notified to boil all drinking water until the water supply is known to be safe.

Bacteriological Analysis

The traditional test for coliform bacteria is the multiple-tube fermentation test. A newer test using membrane filters is an acceptable alternative according to the World Health Organization. The membrane filter test is convenient for field use and has two principle advantages: rapidity and portability. Results are available in 24 hours in contrast to the 48-96 hours required for the standard fermentation-tube method. Membrane filter equipment for bacteriological examination of water is available in field kits from at least two manufacturers.

Minimum Chlorine Residual Concentrations Required for Effective Disinfection of Water

pH of Water	Free Residual Chlorine (mg litre) Minimum Contact Time of 10 min	Combined Residual Chlorine (mg litre) Minimum Contact Time of 60 min
6.0 - 7.0	0.2	1.0
7.0 - 8.0	0.2	1.5
8.0 - 9.0	0.4	1.8
9.0 - 10.0	0.8	not recommended
over 10.0	0.8 (with longer contact period)	not recommended

Source: WHO, 1976

Substitution of chlorine residual testing for bacteriological testing is permissible provided the following points are determined:

For samples in which chlorine residual determination is to be substituted for bacteriological examination, the number of samples needed, the frequency of sampling, and the location of sampling points;

The minimum concentration and type of chlorine residual to be maintained;

The analytical method to be used.

Laboratory tests needed to control treatment processes should be provided at all filter plants. The minimum requirements for tests include turbidity measurements, color determinations, flocculation characteristics (jar test), chlorine demand, and residual chlorine levels.

Tests for pH, alkalinity, and ammonia may be included among the basic tests in order that the effectiveness of coagulation, sedimentation, filtration, chlorination, and corrosion prevention may be determined. Rapid changes in these parameters and others such as chlorides, nitrates, or conductivity indicate possible pollution in the watershed, and a sanitary survey should be made and appropriate remedial action taken. Tests for iron and manganese are necessary when these substances are present in the raw water in sufficient concentrations to influence the treatment processes. Testing for flourides is necessary when flouridation is practiced.

Chemical Surveillance

Chemical surveillance of drinking water assumes greater importance as more raw water sources are exposed to municipal, industrial, and agricultural waste discharges. Water supply personnel should routinely perform chemical and physical tests for proper operational control (residual chlorine levels, pH determinations, turbidity measurements, etc.). However, many laboratories do not have either the personnel or facilities for making some of the important chemical analyses required. In such cases the surveillance agency should assume responsibility for sampling and analysis to ensure that water of satisfactory quality is delivered to consumers.

Complete chemical analysis should include analyses for toxic metals, pesticides, persistent organic chemcials, and radioactivity. In a well equipped laboratory with skilled personnel, chemical analysis of a single surface water sample could require four or more man-days in contrast to less than one man-day for bacteriological and physical analysis only. Where water supplies are obtained from sources with limited exposure to industrial and agricultural wastes, full analysis should be limited mainly to selected sources for large systems, and to occasional sampling.

Once a complete chemical laboratory analysis has been performed and evaluated, many systems may thereafter rely on portable comparators and test kits for determinations of aluminium residual chlorine, flouride, iron, manganese, phosphate and polyphosphate, alkalinity, calcium, hardness, pH, turbidity, and color. In this way manpower requirements per sample analyzed are reduced and the numbers of samples that can be analyzed, or systems surveyed, increased.

Water samples must reach the laboratory with the least delay, preferably within 24 hours. In many countries, sample collectors often do not have personal vehicles and special arrangements may have to be made for transporting of samples. Use of public carriers, buses and even trains, boats and aircraft) has been successful in some areas, but not where the sample collector has to pay the charges from his own pocket. Availability of transport for samples is a key factor in the location of regional laboratories.

There is an obvious need for coordination between sample collectors and laboratory personnel. Unfortunately, samples often are left at transportation points and remain there several days before being collected. In addition, samples may reach laboratories at weekends, when they are closed. A properly coordinated schedule must be established for the shipment of samples and their receipt and examination by laboratory personnel.

Organizational Structure

The surveillance agency should provide the professional services to ensure that the health of the public is protected with regard to drinking water. Additional functions of surveillance agencies include training of water treatment plant chemists; provision of reference standards; certification of water treatment plant laboratories; resale of culture media and other imported supplies to waterworks; evaluation of the safety of waterworks materials and chemicals, e.g., coagulant aids.

Combining the water production and surveillance functions in a single agency is sometimes proposed. Examples exist especially in rural areas. The effectiveness of such arrangements is highly questionable. Experience indicates that the development of complacency is discouraged and greater awareness of the need for surveillance is promoted by the awareness that all activities, whether a financial audit or a sanitary survey are subject to external review. The standards of operations of large, complex, and well run city water supply firms having their own qualified staff can be so high that the surveillance duties of the health authorities can be reduced to a minimum. In such cases, the surveillance agency will be able to give more of its attention to supply systems with poorer internal surveillance. For example, in small rural or locally operated water systems unable to afford qualified managerial or technical personnel the surveillance provided by the central agency may be the only check on water quality. In areas without public water supplies the surveillance agency may be able to reduce grosser hazards of water-borne epidemics through advice and technical assistance.

There is no single pattern of effective organization that can be applied to surveillance operations. Administrative arrangements exist as a function of political structures, economic development, demographic patterns, level of water supply services and other variables that differ from country to country. The important criterion is whether the organization provides effective surveillance.

Several questions that should be asked in the assessment of surveillance agencies to determine their effectiveness follow.

- Is regular surveillance being provided?
- Does the agency have legal delegation of authority and responsibility?
- Does the agency have effective leadership?
- Are there clear lines of authority and review in the agency?
- Does the agency have legal enforcement powers? Are they effective?
- Does the agency have adequate resources?
- Does the agency report periodically to the government on the public health aspects of water supplies.?

The development or strengthening of a surveillance program would not await the creation of an ideal organizational structure. Too often new situations are met by reorganization which usually produces inefficiency and confusion while creating an illusion of progress.

Assessment: Rural Water Supply

Although there is a high degree of variability in the status of water supplies in rural areas, this section is directed to those where a large majority of people do not have a safe and sufficient access to drinking water. The requirements recommended by Rajagopalan (1974) for assessing the status of existing water supply in rural areas include the following: (1) an inventory of communities within a country or region, (2) the establishment of problem or priority areas, and (3) a sanitary survey of existing supplies. These are discussed in the following section.

A survey and inventory of rural communities is useful in establishing local water use patterns and how they relate to other aspects of basic sanitation. These data may then be used to establish priorities for improvement. The factors to be included in such an inventory include the following: (1) details of the locations, (2) the degree of local community organization, (3) details of the existing water supply and source, (4) the nature and quality of all nearby water sources, (5) wastewater, solid waste, and excreta disposal facilities, (6) epidemiological data on the health status, incidence of disease, mortality and morbidity rates, and endemicity of cholera, (7) communication facilities, (8) degree of contact with mass media, and (9) other relevant local factors. (Rajagopalan, 1974)

Specific data on water supply should include the type of source, whether the source is protected, and where piped supplies exist, the adequacy of transmission, storage, and distribution. Once the preliminary data are collected, priorities should be established. High priorities may include slum and "fringe" areas of urban cities, and rural communities in waterborne-disease endemic areas, etc.

Following selection of priority areas, sanitary surveys of existing supplies should be performed. The purpose of these surveys is to determine defects or deficiencies in the system with respect to quality, quantity, and availability. Additionally, these should provide alternatives for improvement and maintenance of the system. The survey should also include an engineering evaluation of potential alternative sources of water.

The typical systems used in rural areas include wells such as step wells, dug wells, tube wells, and drilled wells; rivers, springs, ponds, and irrigation ditches. Rajagopalan (1974) has provided guidelines for use in identifying problems and appropriate solutions with common types of rural water supply and these will be discussed in the following section.

The nature of the construction of the step well easily facilitates contamination since users can step into the water. Helminthic diseases, such as dracontiasis are then easily spread through the water. Exhibit 1 illustrates a step well and the means for its pollution. Step wells should therefore be converted into draw wells by constructing a high parapet all round and an impervious apron. (Rajagopalan)

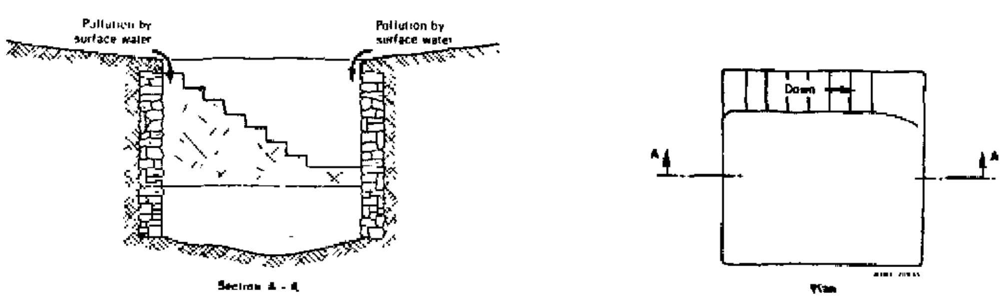
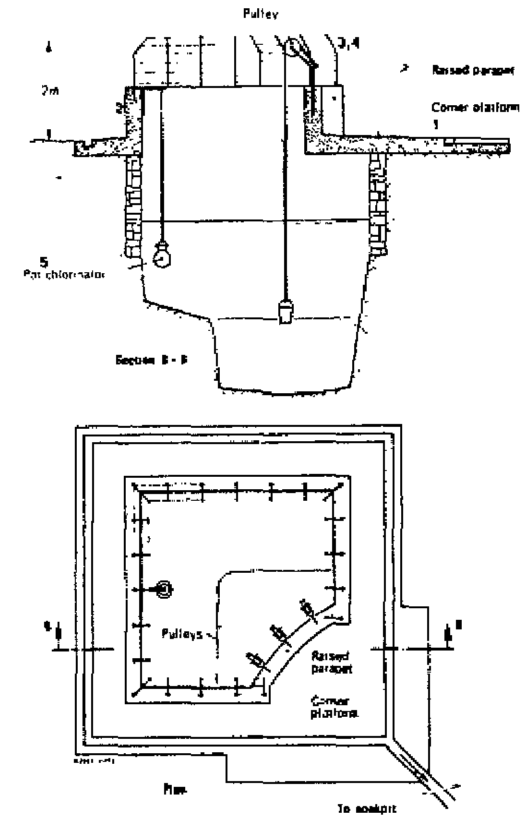


Exhibit 1: Insanitary step-well
Source: Rajagopalan & Shiffman



Check list

1. Is there an impervious apron to exclude surface water?
2. Is there a parapet to prevent users from entering the well?
3. Is step-well converted into draw or pumped well?
4. Are the ropes and buckets permanently installed?
5. Is the well water chlorinated?

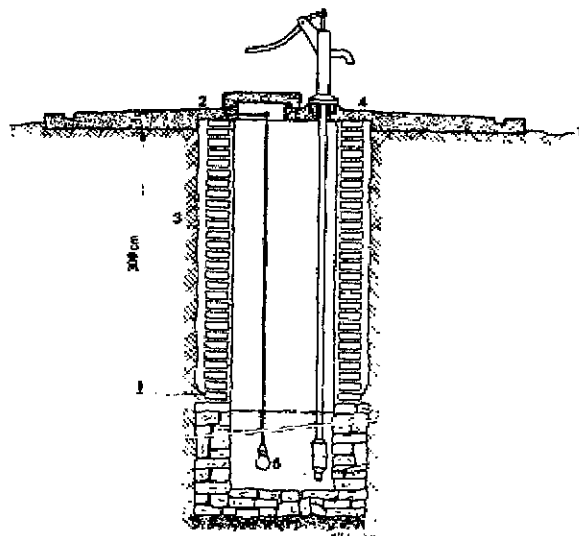
Exhibit 2

When pulley and bucket arrangements are used, pulleys should be installed over a high parapet on the corner platform. Spill water is collected in a peripheral drain for disposal in a soakpit. The checklist at the bottom of Exhibit 2 provides pertinent questions in assessing the adequacy of the well. The yield of large step wells may be improved by deepening in those areas where local hydrogeological factors are favorable.

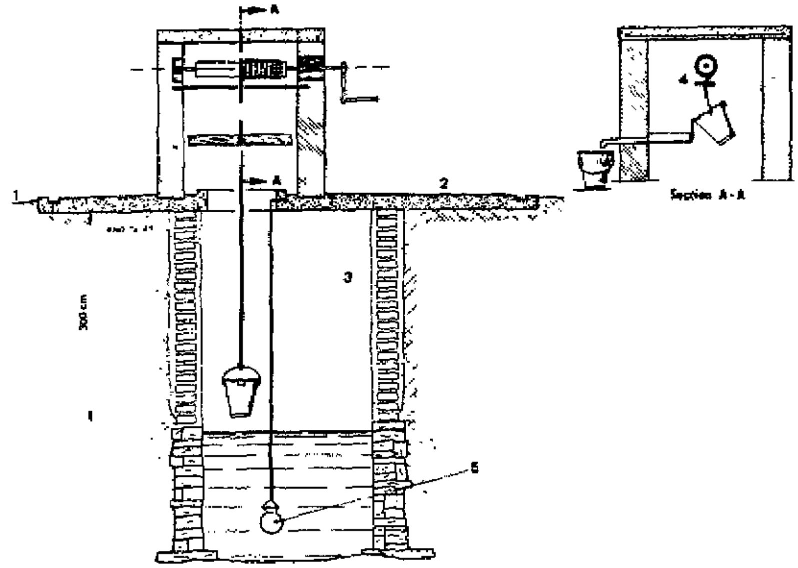
The construction and ultimate yield of a dug well is intimately related to soil type. Soft permeable soils allow for the construction of "sunk wells" which generally yield larger and more dependable supplies. Two types of dug wells, one with a pump and the other with a windlass are illustrated in Exhibits 3 and 4.

Factors to be considered in the sanitary maintenance of each are enumerated in the respective checklists. Additional improvements to dug wells adapted to specific regions or soil types have been developed. (Rajagopalan, 1974) These include the use of weep holes and radial strainers to increase the yield in porous soils.

Exhibits 3 & 4



Check list
1. Is the nearby area free from liquid wastes and privies?
2. Is there an impervious apron to exclude surface water?
3. Are the sides of the well sealed watertight for 3 m below ground level?
4. Is the eduction pipe to pump sealed in apron at exit?
5. Is the well water chlorinated?



Check list
1. Is the nearby area free from liquid wastes and privies?
2. Is there an impervious apron to exclude surface water?
3. Are the sides of the well sealed for 3 m below ground level?
4. Are the rope and bucket inaccessible to the users?
5. Is the well water chlorinated?

Shallow tube wells, or driven wells, are valuable in soft soils or sand, particularly in delta areas where the water supply is sparse. Exhibit 5 shows a tube well and the sanitary precautions that should be checked.

Plain tubing should extend to a depth of three meters, the perforations being confined to the lower depths. A watertight concrete platform with a drain all round should be provided. The area within 15 meters of a tube well should be kept free from pollution with liquid and solid wastes. The hand pump should be kept in good repair and leaks should be prevented.

A perforated jacket is usually provided to cover the wire gauze in the aquifer portion. "Sand blows" may indicate damage sustained while the well is being driven or any subsequent subsoil subsidence. A detailed examination may be necessary to decide whether repair or relocation of the well is needed.

If tube wells are properly constructed with precautions against seepage, they should not become polluted with the infective agents of enteric diseases. Disinfection of these wells is not feasible. Frequent bacteriological checks of the water are, however, essential.

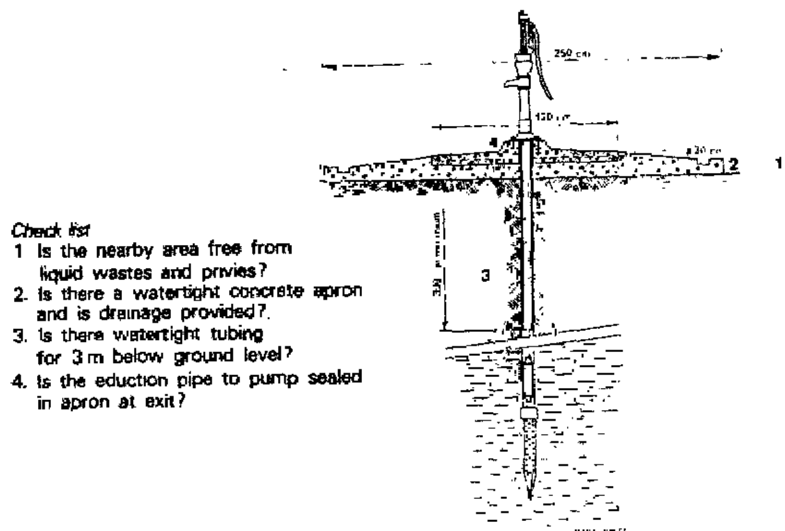
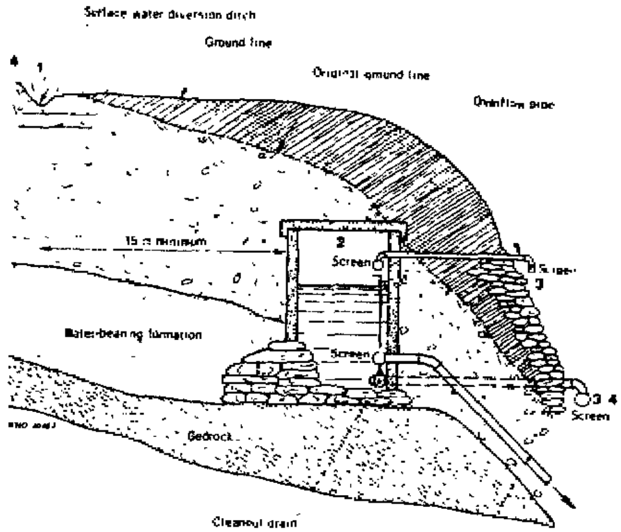


Exhibit 5: Tube well (Source: Rajagopalan & Shiffman)

Deep drilled wells should normally be free from disease producing agents, although contamination may occur through the pump parts or at the delivery points. Quality surveillance of the supply at the delivery points should provide adequate safeguards as an emergency control measure.

Ground water emerging as springs often provides a satisfactory source of water for nearby communities. Sanitary measures are important in the area around the source to keep the supply safe. A masonry chamber, placed so as to intercept the flow, will provide the take-off point. The supply can then be piped to a distribution tank near the community. Chlorination is desirable in emergencies. Exhibit 6 shows a protected spring source and a checklist of the necessary sanitary precautions.



Check list
1 Is there a diversion ditch around the spring to divert surface water?
2. Is the collection structure inaccessible to users?
3. Is drainage provided below the outlet pipes?
4 Are animals excluded by fencing of spring area?

Exhibit 6: Protected spring source
Source: Rajagopalan and Shiffman

The efficacy of the measures described above depends to a large extent on the willing participation of the consumers in observing certain basic precautions at the individual and family level. Strict cleanliness should be enforced in the vicinity of the well-points; personal ablutions, washing of clothes and animals, and the dumping of refuse and wastes should be prohibited. Ropes and buckets from individual homes should not be used for drawing a supply from the well. Water from the well-point should be carried in clean sanitary vessels to individual houses, where it should be stored in clean covered containers. Long-handle dippers should be used to avoid contamination of the stored water. A measure of personal hygiene relevant to these requirements should be taught by health education and through the mass media.

Planning: Drinking Water Supply

Successful planning for a safe drinking-water supply is the result of a thorough assessment of environmental data, health data, facilities, supplies, money, material, and manpower. There are certain preliminary factors that impact on the ultimate success of planning any public health program. These factors are government support, bureaucratic infrastructure, community support and participation, financial resources, and manpower resources.

Dietrich (1976) has addressed the particular role of these factors in successful planning for drinking water supplies. "Government support. Strong government commitment and support is a major prerequisite for the success of any development program. Clear examples are found in countries (like the Dominican Republic and Brazil) where, by establishing a national institution and policy and by implementing a dynamic program of education, consultation, stimulation, and organization of the communities benefiting, success was ensured. Close technical supervision at all levels, fullest exploitation of economies of scale wherever possible, and the development of financial and managerial procedures tailored to local needs are among the items deserving full government support.

"Institutional building— infrastructure. Experience from early ventures in the development of water supply programs has shown that the most common reason for failure in follow-up on investment in developing countries was the absence of a sound and viable organizational structure.

"The provision of water supplies requires substantial amounts of capital, and the physical plants represent a large portion of a country's infrastructure assets, both to protect the investment from deterioration and to provide for its effective operation and maintenance. Continuous and sound management is, therefore, essential.

"In developing countries, the infrastructure for planning, implementation, management, administration, and evaluation of national programs falls within the purview of more than one ministry. Hence, major coordination is required to maximize the efficiency of this important area or function.

"Community participation— Increasingly evident is that one of the main reasons for the slow development of water supply programs is the lack of community participation and motivation. On the other hand, any visions of a global solution of the community water-supply problem will remain a wishful dream without a strong involvement of the community to be served and a determined self-help approach.

"The first step in any community water supply program should be to determine the willingness and interest of the community in the undertaking; secondly, the capability of contributing to the costs of construction in labor and cash; and thirdly, the capability of the community of managing the system and collecting revenues for operation and maintenance.

"Implicit in the above is the great need for community workers, health educators, sanitarians, and others to motivate people and develop a demand for water-supply service in the community. Last but not least, ways and means also should be found to motivate the policy and decision makers. This could be achieved by producing well prepared project-feasibility reports in which cost-benefit and financial-economic studies are well documented and easy to understand with a view to assisting the decision making process.

"Financial resources. Lack of funds is generally a common constraint facing every developing country, and the only alternative is to secure outside financing.

"Often, however, the country does not succeed in trying to obtain foreign funds. One of the reasons is poor project formulation and presentation. Countries should be made aware that a prerequisite for assistance to cover the foreign exhcange component of a project is a comprehensive and well prepared pre-investment survey that would include both economic and engineering feasibility studies. Careful presentation and selection of alternatives and a thorough discussion of the economic and financial aspects involved is essential for lending agencies and decision makers. Projects so presented have found acceptance in national development plans and have attracted outside investment from national, international and bilateral lending agencies.

"Cooperatives, housing banks, lotteries, revolving funds, to name a few, means of support have all been used successfully in securing funds for water-supply programs. Where the economy level is low, the government is obliged to subsidize. Operation and maintenance, however, must be accepted by the community as their responsibility.

"Manpower resources. The importance of skilled manpower in the development of any water supply program is most evident and has been dealt with earlier. Unfortunately the majority of countries in the developing world are faced with the problem of lack of competent personnel both at the professional and subprofessional level. Though the involvement of UN agencies in improving the quality and numbers of manpower available for water-supply work has been consistent, it is far from meeting the needs of the countries.

"Training of nationals both at professional and subprofessional levels has always been one of the main objectives of practically every WHO-assisted environmental health project. Training for subprofessionals is generally carried out at schools of sanitation. As for professionals, courses in sanitary engineering have been conducted at nearly 25 engineering centers, including the universities of Nairobi, Lagos, Zaire, Kumassi, Ankara, Tangoon, Bandung, Bangkok, Chile, Bolivia, Peru, Lahore, Tehran, Rabat. Funds for training pruposes in many cases are provided by UNDP and also by UNICEF for equipment and supplies.

"Though methods of training vary in different countries, the type of personnel required is about the same and includes civil and sanitary engineers health inspectors, water-treatment plant operators, mechanics, plumbers, masons, carpenters, administrators, accountants, and clerks. To train such a vast quantity of personnel also requires availability of professors, trainees, educational institutes, teaching materials, and funds that are woefully inadequate in most developing countries. On the other hand, one also has to guard against merely formal classroom training with no in-service experience under supervision.

"Considerable progress has been made, particularly in Latin America and in some countries in southeast Asia. Concerted efforts, however, by the respective governments in collaboration with international agencies will be required for most countries for many years to come.

"Technology. In practically every situation related to the planning and design of water-supply projects, the technical aspects and the technology involved are known and there is an abundance of knowledge and experience in the field. All the same, often systems are planned and designed poorly and the costs inflated to the ultimate detriment of the country concerned.

"In many instances, alternatives are selected with no economic and financial considerations nor consideration for engineering aspects and the technology applied. This ultimately reflects in the equipment and materials used being far from conducive to conditions prevailing in the country. In this connection the WHO International Reference Center for Community Water Supply at the Hague, through its 30 collaborating institutions in as many countries, ensures that the right know-how and technology is made available on request.

"The main criteria for the selection of systems should be the ability of the community to support the system both financially and otherwise. In other words, the systems should be planned and designed on the basis of what the population is capable of paying in terms of capital recovery and costs of operation and maintenance and not left to the whims of the consulting firms and manufacturers of equipment whose interests may not be those of the community served."

Planning Urban Supply Systems

The technologies involved in the delivery of a safe drinking-water supply fall broadly into the following categories: access and distribution from the source; treatment; and distribution to the community. It must be stressed at this point that the effectiveness of these technologies to prevent ill-health will depend upon the implementation of a surveillance program in conjunction with these technological interventions. Additionally, a critical issue to be resolved is the establishment of appropriate technology; those methods that are feasible for a given community with respect to such factors as financial resources, maintenance personnel, material, and available natural resources; while simultaneously ensuring the protection of the community from potential water-borne diseases. This manual does not suggest the existence of absolute solutions to this issue. Rather, alternative methods and technologies shall be presented here with descriptions of costs and additional features to consider in the decision-making process of planning.

Access to groundwater is certainly the most complicated. It is typically facilitated by wells, springs, and infiltration galleries. A wide variety of technologies exist, for example, in the construction of wells; each differing with respect to technical sophistication, maintenance, applicability to a particular terrain or climate, custom, resources, etc. However, the fundamental issue is clearly the protection of the water from contamination in the well or pump. Here the planner must be concerned, primarily, with three factors; protection of the well from geological hazard, from contamination from surface water, and from proximity to other sources of pollution. The sanitary survey will determine many of these factors and proper sanitation practices will ensure maximum protection. For further information the reader is directed to the reference section where sources of technologies for both rural and urban areas are provided.

A watershed used to supply untreated water should be sparsely inhabited, have no source of pollution, generally be at or near the point of rainfall or snowmelt, and consistently yield clean, clear water. Use of the watershed should be under the control of the water supply authority, and the waterworks staff should make regular and frequent inspections. Even though samples of water from such sources are certified "safe," water entering the ultimate distribution systems should be chlorinated in order to maintain residual protection in the system in case of chance or sporadic contamination of the source.

The waterworks staff must never take the attitude that because the water is subject to treatment or disinfection they are absolved from the necessity of maintaining the best possible raw water quality at the intake. Even the most complete, best operated treatment plant cannot be relied on to operate perfectly at all times; the selection of the purest possible raw water must therefore be considered a necessary preliminary to treatment. This is especially true of intakes from large rivers or open bodies of water. Intakes should be well upstream of sewer outfalls.

The siting and depth of the point at which water enters the supply system may greatly affect water quality. Draw-offs should be sufficiently far below the surface to avoid floating matter. Conversely, an intake set too low may draw in mud and sediment from the bottom. This may interfere with the proper working of pumps and filters. Another hazard is the possibility of counterflow. In an outbreak of infectious hepatitis in 1955, a diversion wall installed to increase the depth of water available caused an upstream eddy in the river as a result of which a waterworks intake received sewage effluent from a discharge some distance downstream.

In cases where the risk is apparent but unavoidable, micro-strainers or coarse sand roughing filters can be installed as a pretreatment precaution, or the intake can be changed to an infiltration gallery along the bank. Another possibility is to construct a raw-water holding reservoir with a capacity of several days' supply where presettlement and some die-off of bacteria may take place. Sediment removal facilities may be necessary for highly turbid raw waters; control of algae may be required in some cases.) Such devices may not only improve the quality of the raw water but, by reducing the load on a treatment plant and stabilizing the quality of the water to be treated, may increase the capacity of the plant quantitatively.

Many failures to meet bacteriological requirements are directly related to the use of poor operating and maintenance procedures for distribution systems or to the presence of sanitary defects in the system. Some causes that contribute to poor bacteriological quality are:

- Insufficient treatment of water at the production plant;
- Cross-connections;
- Improperly protected distribution system storage:
- Inadequate disinfection of water mains and failure to maintain chlorine residuals in the system;
- Unsatisfactory construction and repair of water mains;
- Close proximity of sewers and water mains;
- Improperly constructed, maintained, or located blow-off, vacuum, and air relief valves ;
- Negative or low pressures and intermittent or interrupted flows in the distribution system;
- Improper consumer plumbing practices (direct connection of booster pumps, for example);
- Leakages, especially when combined with low pressures;
- Dead-end mains;
- Faulty hydrants; and
- Faulty maintenance.

Unlike the water source and the treatment and storage installations, much of the distribution system is placed underground and cannot be examined directly. For a sanitary survey, therefore, the maintenance and review of water system records is even more important. Residual chlorine and bacteriological records, both the results of tests and the points of sampling, should be closely inspected. Sampling should emphasize fringe areas and dead-ends within the system. Another useful record series, if available, is a comparison of treated water pumped and water distributed to consumers. If losses exceed about ten percent, and certainly if they exceed thirty percent, leakages and the control of leakage merit further investigation. Records of system pressures, if available, should also be reviewed. Low pressure may result in a flow of polluted water through leaks into pipes and back-siphonage through leaks or improper connections.

One of the most common problems encountered in many water systems is the large quantities of water lost or wasted after entering into the transmission and distribution systems. Losses result from leakage in poorly constructed systems or when pipes become corroded, from illegal connections, from meters which under register, and from records which have been lost on customers receiving service. Because of the economic consequences of large water losses, including the health hazards of poorly maintained systems, technical sections of every water institution need to give high priority to prevention and correction of water losses. Consideration of metering policy should represent a deliberate choice of the extent to which consumer connections are metered. Some practices which may need attention are administration of the billing and collection system, meter reading procedures, measures to avoid graft, illegal connections, and so on.

When the area, or line, in which there is a leak is known, a pipe locator should be used to determine the exact location of the pipe; a listening stick applied directly to the pipe or to the ground surface above a pipe is very effective in transmitting sounds to the ear. Amplifying devices such as stethoscopes or special equipment exist but there is no evidence that pipe locators or amplifiers are better than a listening stick for distinguishing the noise of a leak from other noises, their advantage is that they produce a louder output. (An extensive and useful summary of leak detection in India has been published by the Central Public Health Engineering Research Institute.)

Reservoirs for storing finished waters (service reservoir) should be located above probable groundwater levels and well away from surface runoff and underground drainage. Provision should be made to guard against sanitary hazards related to the location; groundwater levels, movements, and quality; the character of soil; the possibility of pollution by sewage; and overtopping by floods. Sites in ravines or low-lying areas subject to periodic flooding should be avoided. Good practice indicates that sewers located within 15 meters of a storage reservoir with a floor below ground level should be strongly constructed with sound, tested, water-tight joints. No sewer should be located closer than three meters to a reservoir.

A suitable and substantial cover should be provided for any reservoir elevated tank, or other structure used for storing finished water. Covers should be watertight, constructed of permanent materials, provided with handles and locks, and designed to drain freely and prevent contamination of the stored water. Manhole covers should be provided with a sturdy locking device and should be kept locked when not in use. Reservoirs and elevated tanks on the distribution system should be disinfected before being put into service or after extensive repairs or cleaning have been completed. A schedule should be prepared for regular maintenance and inspection.

Of primary concern to the environmental health planner is the treatment of water: that point at which regular action is taken to control potential health hazards. The basic treatment scheme involves coagulation, sedimentation, filtration, and disinfection. All of these processes are recommended for urban communities utilizing surface water as its principal drinking water source. Coagulation is facilitated by the introduction of chemicals known as coagulants. Common coagulants include alum (aluminum sulfate), "black alum," activated alum, ammonium alum, and sodium aluminate.

These substances are typically introduced in two steps: flash or rapid mix and slow mix. The slow mix promotes floc formation; the agglomeration of coagulated material into larger, filterable particles. Enmeshed in the floc are microorganisms, suspended particles, and colloidal material; all of which will settle out during the sedimentation process. The choice of a particular coagulant or coagulants is dependent upon the properties of the water, especially its pH, chemical constituents, color and hardness.

The process of sedimentation occurs naturally, without the addition of chemicals, in all bodies of water, resulting in the settling out of suspended solids. This settling out, however, is escalated by the previously induced flocculation. Sedimentation tank design will vary depending on: the quantity of water; the detention period; and the surface overflow rate. Basically, however, the process is the same.

Filtration is accomplished most frequently by means of either slow sand filtration or rapid sand filtration. However, under certain specialized conditions either pressure filters or diatomaceous-earth filters may be utilized. The selection of any one of these methods will be dependent upon a variety of local factors as well as inherent advantages and disadvantages.

Slow sand filtration involves the gradual flow of water over a large bed of fine sand particles creating a large total surface area for adsorption of impurities. This method is recommended for rural communities. The advantages of slow sand filtration are summarized by Cox in a World Health Organization document (1964).

- There is no need for coagulation facilities.
- Equipment is simple and need not be imported.
- Suitable sand is readily secured.
- Supervision is simple.
- The effluent is less corrosive and more uniform in quality than chemically treated waters.
- They give effective bacterial removal

The disadvantages of slow sand filtration as compared with rapid sand filtration have also been summarized in this publication as follows:

- A large area is required, with correspondingly large structure and volume of sand and higher structural cots.
- They have less flexibility in operation.
- They are not economical with raw waters having turbidities over about 30 units for prolonger periods, unless preliminary plain sedimentation will secure such turbidities in the settled water.
- They are less effective in removing color.
- They give poor results with water of high algal content, unless pre-treatment is practiced."

Slow sand filters are simple to operate, requiring relatively unskilled labor, are generally reliable in terms of filtrate quality, provide water that meets drinking-water standards (assuming reasonable raw water quality), and do not require imported mechanical equipment. Slow sand filtration has been advocated for use in developing countries, especially in small plants with manual cleaning where this may be the sole treatment to which the water is subjected. Extensive guidelines for the operation and inspection of slow sand filters are given by Huisman and Wood. As a biological treatment system, slow sand filters must be used with care. Sudden variations in flow or raw water quality can be harmful. Therefore, it may be necessary to store the water both before and after filtration.

Good bookkeeping is essential for monitoring a slow sand filter. The history of each filter should be established day by day, recording at least the following information:

- the date of last cleaning;
- the date and hour of return to full service (i.e., end of the ripening period);
- raw and filtered water levels (measured each day at the same hour) and the daily loss of hea;
- the filtration rate and the hourly variations, if any occur;
- the quality of the raw water, including temperature, turbidity, color, and bacterial count (in small plants lacking laboratories, bacteriological testing may not be feasible; such situations place even more importance on measurements of turbidity and residual chlorine in finished water samples taken each day at the same hour);
- the same quality parameters for the filtered water; and
- any incidents that may have occurred and which could affect plant operation, such as plankton development, troubles with the "Schmutzdecke" (i.e., biological film), wind and rain, etc.

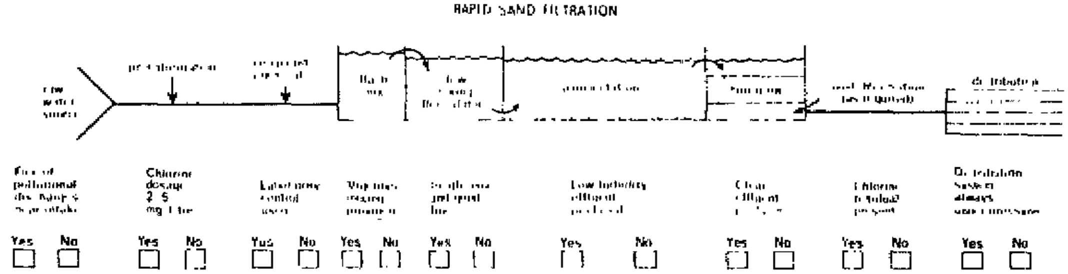
Rapid sand filtration is designed "to receive coagulated and settled water; in these filters colloidal material and bacteria are adsorbed on the gelatinous floc and are removed with the floc." (Cox, 1964). Consequently, the water must be sufficiently pretreated for this method to be effective. In the establishment of rapid sand filtration facilities particular attention should be paid to the availability of power sources and trained personnel as well as other local factors.

The operation and control of rapid sand filters is described in detail in Operation and Control of Water Treatment Processes. The operation of filters should be controlled by tests for turbidity and color and by bacteriological examinations of the water. The objective should be to produce water with a turbidity of less than 0.5 Jackson units (JTU). In well operated plants turbidity will not normally exceed 1.0 JTU; turbidities greater than 5 JTU are detectable by consumers. Rapid sand and slow sand filtration processes require regular monitoring and surveillance. Exhibit 7 presents a checklist for proper surveillance of these processes.

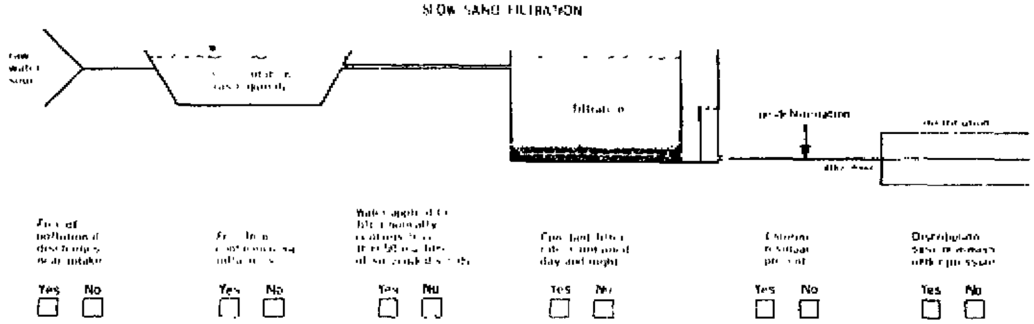
Pressure filters operate by the same basic principles as the gravity promoted sand filters. However, the process takes place in steel cylinders designed to withstand high water pressure (typically up to 10 atmospheres). This advantage is counteracted by many disadvantages summarized, again by Cox (1964), as follows:

- The treatment of water under pressure seriously complicates effective mixing, coagulation, and sedimentation of the water to be filtered; many pressure filters are thus installed without adequate coagulation facilities.
- It is more difficult to apply chemicals to water under pressure.
- The appearance of the water being filtered and of the sand bed is not under observation, nor is it possible to observe the effectiveness of wash water or the degree of agitation during the washing process.
- Because of the shape of pressure filters it is difficult to provide effectively designed wash-water piping to ensure that material washed from the sand is discharged to waste and not flushed back to other portions of the sand bed.
- It is difficult to inspect clean, and replace the sand, gravel, and underdrains of pressure filters.
- The operation of such units under pressure encourages the pumping or forcing of water through the beds at excessive rates."

RAPID SAND FILTRATION



SLOW SAND FILTRATION



Pressure filters continue to be used for smaller water supplies because they may be assembled in the factory and shipped for immediate installation.

Diatomaceous-earth filters are not typically used for drinking water supplies. They are compact and of relatively low weight thereby proving most useful in emergencies or temporary situations. Their use, however, is only recommended for the clarification of waters of initially low turbidity. Furthermore, diatomaceous-earth is not available everywhere and is costly to import. The advantages and disadvantages of diatomaceous-earth filters have been summarized by Cox (1964).

The advantages of the diatomaceous-earth filter may be summarized as follows:

- There is a large filter area per unit of over-all dimensions.
- Their weight is low compared with pressure sand filters of the same capacity, favoring their use as portable units.
- Waters with turbidities less than about 30 units may be effectively clarified without coagulation.
- The fine powder forms as effective a filter medium for the removal of bacteria, and especially the cysts of dysenteric amoebae, as sand filters coated with alum floc.
- These filters may be operated with one pumping operation, as contrasted with raw- and filter-water pumps of gravity sand filters.

The disadvantages of these filters are as follows:

- The units are effective only so long as each precoat is properly applied and the flow is continuous, so they are more dependent on effective operation than are rapid sand filters.
- The loss of head is much higher than with sand filters.
- Diatomaceous earth is not generally available throughout the world.
- Difficulty with clogging of the fine openings of elements presents problems, especially if uncoagulated iron is present in raw waters or if raw water is forced through the elements before an effective precoat is formed.
- These filters have short filter runs if coagulated and settled water is applied, because of clogging by residual alum floc.

Chlorination is, by far, the most commonly performed means of disinfection of water. Other disinfectants include bromine, ozone, and ultraviolet radiation. Although bromine is effective, equipment for its storage and application are less readily available than for chlorine. Furthermore, chlorine and chlorine compounds are less expensive. Ozone has been used in Europe for many years; it effectively removes tastes and odors as well as disinfects. Its use is costly, however, due to the high energy input required to regenerate the ozone. Ultraviolet radiation, also an effective disinfectant, requires a high degree of maintenance and the equipment for its application is costly.

Chlorine functions as a disinfectant by destroying potential pathogens and by providing a protective residual in the water to maintain a certain level of purity.

Its additional functions include: the oxidation of certain compounds such as hydrogen sulfide, manganese, and iron; the destruction of certain odor- and taste-producing substances; the prevention of the growth of algal and slime organisms in treatment plants; and the provision of assistance in the coagulation process. Furthermore, testing a water supply for residual chlorine is an effective means of surveillance. Often in those plants of insufficient size the examination for residual chlorine serves as a substitute for bacteriological analysis.

Under certain circumstances chlorination alone is sufficient treatment of a water source. However, caution must be exercised. Generally speaking, mere chlorination is effective only under the following conditions:

1. the degree of bacteriological pollution is moderate and reasonably uniform, and the bacteria to be destroyed are not shielded from the chlorine by being bedded in suspended solids or within the bodies of worms, for example:
2. the turbidity and color of the water do not exceed 5-10 units;
3. the content of iron or manganese (or both) in the water does not exceed 0.3 p.p.m.;
4. the chlorine demand of the water does not fluctuate so rapidly as to prevent proper adjustment of the chlorine dose;
5. taste- and odor-producing substances are absent or do not interfere with the selection of adequate chlorine doses through the production of chlorine tastes;
6. There is a contact period of at least 15 minutes between the point of chlorination and the house connection of the consumer first supplied with water. Cox (1964).

Most typically, therefore, chlorination is performed in conjunction with the previously mentioned procedures, following filtration, however, prechlorination is commonly performed before coagulation, especially in waters with a high organic content.

Some of the more frequent and preventable sanitary deficiencies that occur in water supply systems are listed below. These lists are neither complete nor universally applicable. The examples provided suggest possibilities for contamination to be anticipated and avoided by appropriate planning, and to be considered during periodic surveys and assessments of existing works or operations.

Groundwater contamination sources include caves, sink holes, or abandoned borings used for surface drainage or sewage disposal in the vicinity of the source; fissures or open faults in strata overlying water-bearing formations; casing of tubular wells leaking or not extended to a sufficient depth, or not extended above ground or floor of pump room, or not closed at top, or casing improperly used as a suction pipe.

Also among groundwater sources are a collecting well or reservoir subject to contamination by back-flow of polluted water through improper drain or by entry of surface drainage, lack of covers; improperly designed manholes, vent openings, etc., that may permit contamination; supply sources or adjacent structures that are subject to flooding; use of tile pipes or other conduits that are not watertight in locations where the groundwater may be contaminated; leaks in systems under vacuum; air-lift line or lines cross-connected to a sewer or secondary water supply.

Other sources of groundwater contamination include wells located near sewers, pit privies, cesspools, septic tanks, subsurface tile systems, drains, barnyards, pits below ground surface, or other sources of contamination; wellheads, well casings, pumps, pumping machinery, exposed suction pipes, or valve boxes connected to suction pipes located in pits extending below the ground surface; manufacturing, industrial, or agricultural plant wastes discharged or spilled on watersheds or into underground strata causing contamination of groundwater supplies.

Failure to disinfect new wells and springs leads to contamination, as does failure to provide sanitary facilities for construction workers; use of pump that is not self-priming; unsafe water used for priming.

Distribution system contamination may stem from intermittent service resulting in reduced or negative pressures in distribution system; sizes of mains and laterals inadequate for preventing negative pressures; presence of dead-ends permitting reduced or negative pressure; lack of provision for maintaining continuity of pumping service under all conditions; repumping on consumer premises when pressure is low, causing negative head; existence of cross-connections between the primary supply and a secondary supply of questionable safety; or presence of a secondary non-potable water system on premises where a public system exists in the absence of adequate regulations and enforcement procedures to prevent the occurrence of cross-connections.

Lack of, or inadequate, enforcement of plumbing regulations and/or ordinances designed to protect the water supply against the possibility of backflow. So can connection of new pipelines to the system without prior disinfection of pipes; unauthorized operation of water supply facilities by persons other than waterworks employees; or existence of leaky pipes in the distribution system.

Improper location of water pipes in relation to sewers and stormwater drains may be the culprit, or return to the system of water used for cooling purposes; connections to sewers and sewer-flushing chambers, and improperly located blow-offs in the distribution system; or inadequate wash-out points to permit distribution mains to be flushed or swabbed; insufficient valves to permit the isolation of different parts of the distribution system.

Distribution system contaminants may also come from poorly designed valve, blow-off, and meter boxes, hydrants, and "pit taps" that may permit puddles or groundwater to accumulate with consequent risk of back-siphonage, spread of helminthic diseases, and breeding of mosquitos; poorly drained and protected street fountains; and defective service reservoirs.

Surface water sources and treatment can be contaminated by excessive raw water pollution in relation to extent of treatment provided; existence of uncontrolled or unidentified sources of pollution such as population on watershed, lumbering, hunting, grazing, and other activities; leaching cesspools or sewers draining into streams or lakes in the catchment area or into adjacent marginal land; also accidental spillage and runoff of herbicides, pesticides, and agricultural chemicals; no restrictions on recreational use of streams and reservoirs on marginal land in the local catchment area.

Similarly, contaminants may come from inadequate sanitary facilities and control of contamination at reservoirs used for recreational purposes; improper location of intakes with respect to bottom of reservoir and current or to inlets for surface drainage water; intakes exposed and accessible to trespassers; improper location of water treatment plant or inadequate protection against flood waters; lack of competent supervision and operation, fault maintenance, or lack of adequate laboratory control.

Lack of proper chlorination equipment invites contamination, as does unreliability of equipment and lack of control; failure to maintain proper chlorine residuals in the treated water at all times; lack of suitable devices for measuring and recording volume of water treated and for maintaining continuity of coagulant and chlorine dosages; deficient retention periods in settling basins or inadequate filtration and backwashing capacity.

Also consider the existence of cross-connections, by-passes, or common concrete channel walls within the plant— between conduits or basins carrying untreated or partly treated water and those containing completely treated water, for example; by-pass connections for raw water or partially treated water, permitting such waters to be discharged into the distribution system; lack of reserve capacity in treatment works, necessitating excessive overloading or occasional by-passing of units.

To these sources should be added: lack of sanitary latrines and washing facilities for waterworks personnel; contamination by infected employees or by unauthorized visitors; inadequate arrangements for cleaning and draining floors, tanks and aprons; lack of suitable protection for purified water, such as a storage capacity less than that required for safety.

Planning Rural Supply Systems

The Assessment and Planning sections on rural water supply are integrally related. Many of the factors to be assessed may be viewed as planning consierations. The following section will describe measures useful in supplying safe drinking water to areas having none. Rajagopalan (1974) provides some simple methods of source development including emergency supplies, emergency distribution systems, and prevention of pollution.

It is possible to improvise safe water supplies for special endemic and problem areas where no supply exists. The inventory of rural communities referred to earlier will help to identify areas where the provision of a safe water supply would be possible. Some simple methods of source development for rural systems are indicated below.

Dug wells are suitable for water-bearing formations of adequate extent and porosity. The yield is governed more by the depth than the diameter of the well. The provision of weep holes and radial strainers will increase the yield.

Tube wells are very suitable in deltaic regions with deep deposits of alluvium. Where cholera is endemic, several suitably located shallow tube wells will help to protect the population from epidemic cholera. Instructions for the construction of tube wells were given by Wagner and Lanoix (1959). It should be pointed out that the often recommended procedure of forcibly driving in the pipes for shallow tube wells (7.5 m) with the aid of wrenches is unsatisfactory as it results in damaging the well point or clogging it with earth. Investigations have shown (Pollizer, 1949) that water from this type of well remains safe even when surface conditions are insanitary.

The ready availability of a nearby unsafe water source, such as a local pond or irrigation canal poses a health risk to the community. The abstraction of a safe supply from such polluted sources is essential.

An infiltration gallery in the bed of a pond that filters the raw water and delivers it into a well located at the margin of the pond is one such way. This well can provide a safe supply through hand pumps, keeping in mind that sediment builds up on top of the gallery, which may retard the subsequent free passage of water. The surface silty layer should therefore be removed periodically. The cross-section and length of the gallery should depend on the quantity and rate of draw at the well. Normally a gallery 2.5 x 2.5 x 10 m should be able to provide about 10,000 liters per day.

It may be possible to install an infiltration gallery in a canal bed either across or along the course of the canal with a suitable clear-water collecting well by the bank. If the canal is unsuitable for this purpose (because of size or other limitations) it may be feasible to draw off a supply of raw water through a pipe into a bypass channel and pass this water through a filtration gallery.

In certain places a tunnel driven into a waterbearing stratum can function as an infiltration gallery, the collected water being led out by gravity. Comparatively firm but porous subsoil layers in undulating country near the foot of a range of hills might be suitable for such a system. However, the construction may be slow and expensive. This system of water collection is common in the eastern Mediterranean area and in North Africa (the galleries are called "Karez" or "Khanat" in Iraq and Iran).

An infiltration well sunk in the sandy bed of a river can provide an economical and dependable safe supply of water. Such wells are usually at least three meters in diameter. The cost of the well increases with increase in diameter more rapidly than does the yield; the depth is governed by the depth of the waterbearing stratum and the required yield. The provision of weep holes in the well-lining below the draw-off level, or the insertion of radial strainers at the lower levels, would increase the yield.

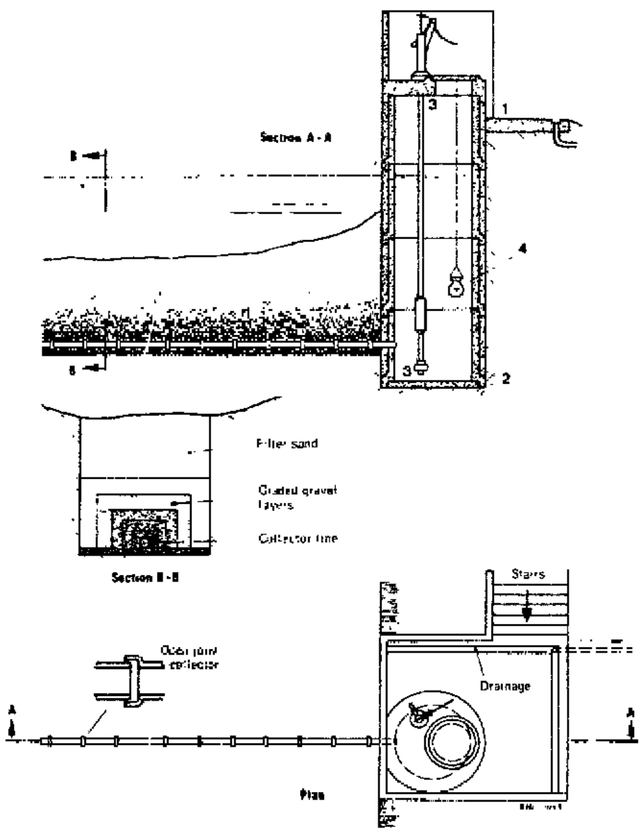
Porous plugs placed at the bottom of such wells after the initial "training of the yield" facilitate the abstraction of a greater yield by permitting increased velocities of entry without "sand blows." The plug functions as an inverted filter comprising suitably graded coarse sand and broken stone, the depth and composition being designed to suit the texture of the subsoil layers and to maintain the layers immediately below the curb level undisturbed during pumping. Wells in sandy river beds should be taken well below the maximum scour range to prevent subsidence and damage to the well during high flood flows.

Multiple wells suitably arranged in a sandy river bed increase the yield obtainable from the source at a single pumping point. A system of wells with interconnecting pipes across the course of the river to arrest the subsurface flow, or along a ground water contour is a satisfactory arrangement. The spacing of such wells is governed by the need to reduce mutual interference to a minimum and the cost of constructing the wells and of the piping and the frictional losses up to the pump head. Submersible pumps operating on individual wells would provide greater latitude.

Galleries are better than a system of wells, as they help to arrest the subsoil flow along their entire length with a comparatively lower drawdown, and avoid the necessity for an expensive interconnecting pipe system deep in the river bed. The alignment, structure, and placement of a gallery in the river bed should be decided in relation to the texture of the subsoil layers, the scour zone, the supply required, and the safe drawdown.

In rivers where there are seasonal variations in surface flow, a subsurface impervious barrage placed across the river downstream of the infiltration works would help to raise the level of the subsurface flow and facilitate abstratction of the supply.

An impervious, hard, or rocky river bed may preclude the abstraction of a safe supply from any type of infiltration system placed in the river bed. Other raw water sources may also pose the same problem. Surface treatment measures may be necessary in such cases to render the raw water potable for a community supply and it is worthwhile examining the nature and physical quality of the raw water to see whether slow sand filtration would be satisfactory as a final treatment, with plain sedimentation (aided by chemicals if required) as a preliminary treatment.

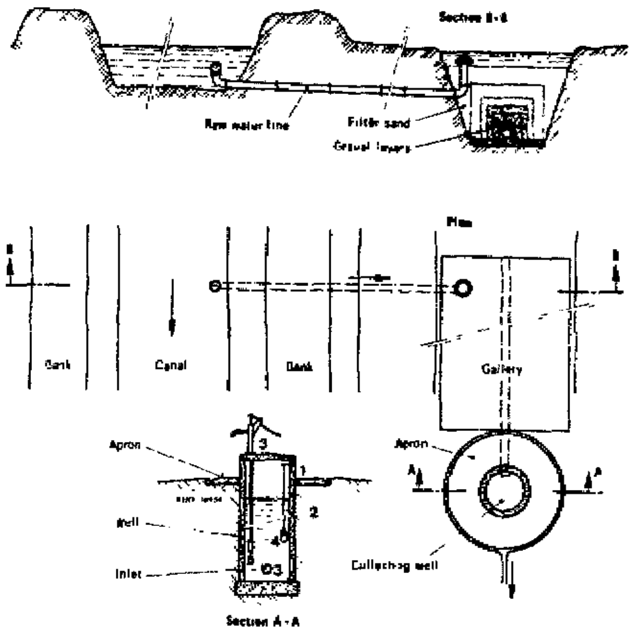


Check list

1. Does the collecting well extend 1 m above ground?
2. Is the collecting well sealed watertight throughout?
3. Are the inlet and outlet pipes well sealed in place?
4. Is the water chlorinated?

Exhibit 8 Infiltration Gallery in Village Pond

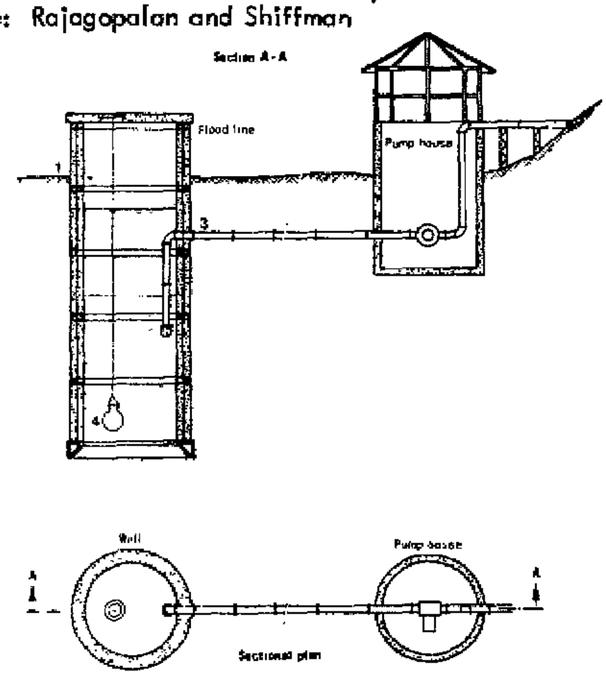
Source: Rajagopalan and Shiffman



Check list

1. Does the collecting well extend 1 m above ground?
2. Is the collecting well sealed watertight throughout?
3. Are the inlet and outlet pipes well sealed in place?
4. Is the water chlorinated?

Exhibit 9 Infiltration Gallery for Canal
Source: Rajagopalan and Shiffman



Check list

1. Does the infiltration well extend above mean flood level?
2. Are the sides of the well sealed watertight to the bottom?
3. Is the outlet pipe well sealed in place?
4. Is the water chlorinated?

Exhibit 10 Infiltration Well in River Bed, and Pump House

Source: Rajagopalan and Shiffman

Where emergency supplies can be made available by improvements at the source and the treatment works, it is necessary to provide for the distribution of such supplies to the consumer areas. The proximity of an available safe supply usually decides the extent to which it is used by a rural community, particularly when unsafe sources are more easily available. It is therefore advisable to investigate all the possibilities of making the supply easily accessible to the rural consumer. It may be possible temporarily to increase the carrying capacity of existing transmission mains by lowering the end delivery point, by duplicating part of the main, by intermediate boosting, or even by diverting part of the supply to serve nearby areas ahead of a centrally located elevated service storage. The hazards inherent in ill-served and unserved areas, even if rural, should be overcome by providing temporary distribution points in extended pipelines, or, as an alternative, small distribution tanks mounted on cribs with a number of well distributed taps to serve as many consumers as possible within an "accessible zone." Water tankers should be used for the distribution of safe water only in needy areas where no other provision has been possible, so releasing available water tankers to serve problem areas without a source and without a supply.

The distribution of water to needy areas by powered vehicles is expensive and can be justified only in an emergency. It should not engender a relaxation of the efforts to implement a planned program of simple measures to deal with water shortage in endemic and problem areas.

Water tankers should be designed and built to ensure the safe quality of the water at all stages. Drawing, hauling, and delivery arrangements should be proofed against contamination. The interior of the water containers should be smooth, free from dust, and rust-proof and the drain plug should be protected by a sanitary seal. It is essential to ensure that the tanker is filled from a safe source in a hygienic manner and that the operating crew are not carriers of pathogens. It is equally essential to provide chlorinating equipment (either at the filling place or with the tanker) so that the water can be effectively disinfected, and has a free chlorine residual of not less than 0.2 miligrams per liter when delivered to the consumers.

Water is heavy to haul and the percapita distribution may have to be restricted to drinking and culinary needs. Such limitation may defeat the objects of distributing water; it may result in poor personal hygiene and sanitary discipline, and may transfer the transmission route to food and filth. Health education is particularly necessary under such emergency conditions.

As an ad hoc arrangement to produce safe water from raw water sources to serve the emergency needs of a local community or a fair, portable water treatment plants mounted on a truck are suitable. Usually, such a plant includes: a centrifugal pump directly coupled to a petrol engine; a rapid sand filter unit (of the pressure type); chemical solution tanks (one for alum and one for soda ash); a chlorine solution tank; a hypochlorinator; hose adapters; valves (pump suction inlet, drain, air-release, outlet, and flow control); and an instruction manual for guidance in operation and handling. The device aims at chemically treating the raw water and passing it through a pressure filter without prior sedimentation. Effective chlorination of the effluent must be available in emergencies to protect against deficiencies in the process.

Supplies drawn from polluted domestic wells and individual dwellings can result in spread of enteric diseases at the community level. Three methods are generally available for purifying water on an individual or domestic scale: boiling, chemical disinfection, and filtration.

Boiling yields total sterilization of the water against all bacteria, spores, cercariae, cysts, and ova. To be effective however, the water must be brought to a "rolling boil" for five minutes.

Chemical disinfection. The water can be disinfected in the well or in intermediate storage containers by appropriate methods described elsewhere. One of the easily obtainable materials containing chlorine may be used for the purpose.

Filtration. A household sand filter is not foolproof. Ceramic filters are to be preferred, since the water to be treated is usually clear. With turbid water, prior clarification through a sand filter is necessary. Coarse-grained filter candles are useful to remove suspended matter, helminth ova, cercariae, and cysts; they are only partially effective in the removal of pathogenic bacteria. To be satisfactory for water purification, the maximum pore diameter of a porcelain filter candle should be 1.5 m. Infusorial (diatomaceous earth) filters are equally effective, if the finer grained candles are adopted for efficient bacterial filtration. Filters and their attachments should be carefully examined at frequent intervals to guard against cracks or leaks. The filters must be cleaned and boiled at intervals. Proprietary filters often generate a false sense of security in developing countries, while lack of maintenance and unsafe handling practices detract from their value. These household methods can never be relied upon on a community scale.

The Decision to Treat

The decision to treat a particular water supply is related to quality and quantity factors as well as costs, manpower, material, equipment, etc. Alternatives therefore must be considered, including either the supplying of untreated water, as is, supplying untreated water after 48 hours standing, or abandonment of the source. Feachem (1977) has provided an algorithm of the decision process to treat, not to treat, or to abandon a particular source, presented in Exhibit 11. The decision process should be carefully studied as an example of needed planning issues or questions to be raised in developing any rural drinking water supply. The criteria on which he bases these judgments are described as follows:

a	E. coli per 100 ml	Supply untreated
a-b	E. coli per 100 ml	Treat if possible, if not supply untreated
b-c	E. coli per 100 m.	Treat if possible, if not supply untreated or abandon depending on various other factors
c	E. coli per 100 ml	Treat if possible, if not abandon or supply untreated depending on various other factors

The values of a, b, and c may vary with local conditions and with increasing knowledge. However, Feachem suggests that a equal 10, b equal 100, and c equal 1,000. This approach may be most helpful in rural communities.

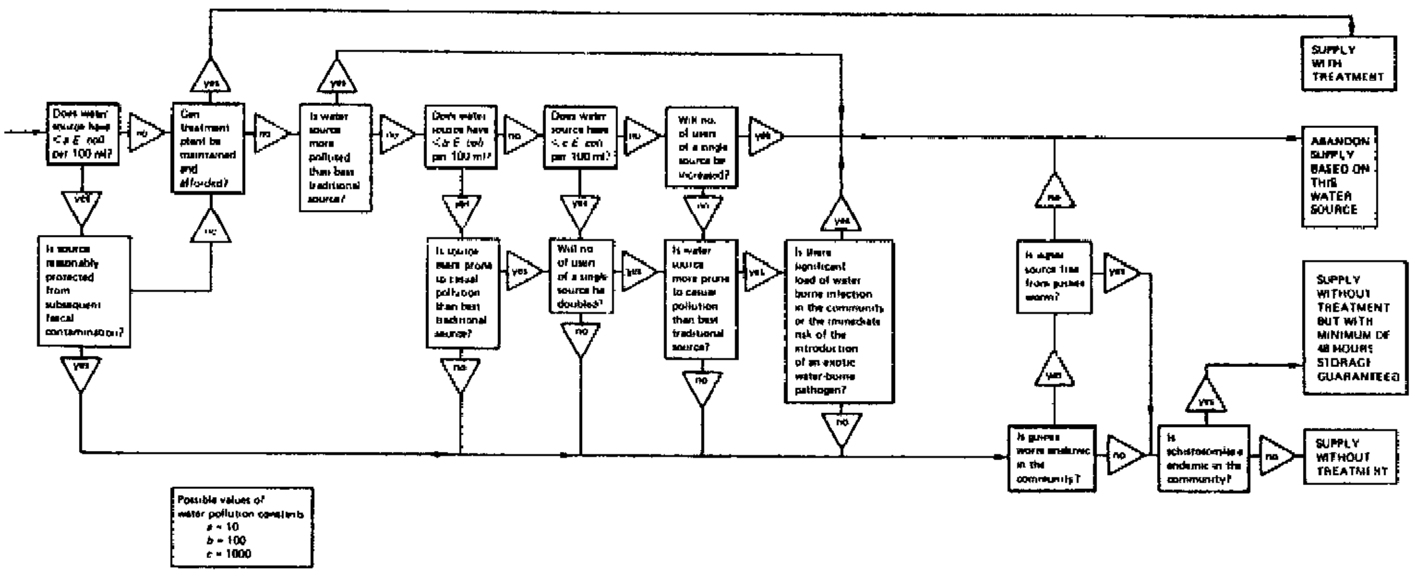


Exhibit 11 An Algorithm of the Decision to Treat, Not to Treat, or to Abandon a Particular Water Source

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