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SURVEILLANCE OF DRINKING-WATER QUALITY

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PREFACE

For some time the World Health Organization has been concerned about the lack of a single, comprehensive, but concise, source of practical information about, and guidelines for, public health surveillance of drinking-water quality in the developing countries. Surprisingly, few comprehensive studies of this subject have been undertaken, and there are few developing countries where formally organized, nationwide, fully adequate, and effective surveillance programmes have been implemented.

Major efforts have been made, and more are underway, to provide safe and convenient piped water supplies to many of the world's population. The benefits of safe and adequate drinking-water supplies are not automatically assured with the construction of waterworks and distribution systems. Indeed, experience has shown that without proper surveillance the water supply system itself may become an effective channel for spreading disease.

In this publication are assembled information and guidelines for planning, organizing, and operating programmes for surveillance of drinking-water quality at the national or regional level in the developing countries. The monograph is intended for use by officials with public health responsibilities and those responsible for the production and distribution of drinking-water, engineers and sanitarians engaged in public health or water supply activities, water treatment plant operators, and other persons who have a professional interest in water supply.

The guidelines presented here originated from a study of methods and procedures for the surveillance of drinking-water quality in developing countries initiated in 1968 under an arrangement between WHO and the University of North Carolina at Chapel Hill, USA, with Professor F. E. McJunkin as principal investigator. Information was obtained through on-site reviews of surveillance programmes in some eight countries; from correspondence and interviews with health and water supply officials and members of the WHO secretariat dealing with problems of environmental health; from comments and suggestions made by the panel of reviewers; by review of WHO publications and unpublished documents, especially country reports, questionnaires, and cholera team reports; and by review of the technical and scientific literature.

A draft of the guidelines prepared by Professor McJunkin was circulated to a number of reviewers and revised in the light of their comments and suggestions; a list of the reviewers is given in Annex 10. The revised draft was then discussed at a meeting of advisers convened in Geneva from 18 to 24 February 1975, when the guidelines were finalized. The names of those who participated in the meeting *are listed in Annex 9. The World Health Organization is grateful to the reviewers and advisers, and particularly to Professor McJunkin, for their efforts in formulating these guidelines.*

The feasibility of each concept presented here has been demonstrated under operational conditions. However, no guidelines of a general character can be used rigidly or arbitrarily and without exception; progressive innovation should always be encouraged. Nevertheless, major departures from the proposed guidelines and concepts should be reviewed critically.

In addition to effective surveillance, well planned, designed, operated, and maintained water systems are essential in providing safe, wholesome water supplies. Interested readers will find much useful information on these aspects of water supply in four WHO publications: Water supply for rural areas and small communities (28), Operation and control of water treatment processes (17), Slow sand filtration (29), *and* International standards for drinking-water (10).

1. Introduction

Surveillance

Surveillance of drinking-water quality can be defined as "the continuous and vigilant public health assessment and overview of the safety and acceptability of drinking-water supplies". Public health protection of drinking-water supplies should assure that each component of the system—source, treatment, storage, and distribution—functions without risk of failure. Flawless treatment serves no purpose if the distribution system permits contamination through faulty installations or cross-connexions, an excellent distribution system will not protect the public health if the distributed water receives insufficient treatment, while a heavily polluted source may overwhelm the treatment capacity.

The elements of a surveillance programme include engineering and the physical, biological, chemical, and institutional examination of water supplies. The enginering examination or *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 could present a health hazard to the consumer. Physical, biological (generally bacteriological), and chemical examinations include testing of water samples in both the field and the laboratory. Institutional examination concerns those elements of operation and management that may result in health hazards to consumers, e.g., incompetent operators.

Full evaluation of the health risks in a large water system would include, as a minimum, careful and critical examination of the following points:

Quality of source

Output of source

Protection of source

Adequacy and reliability of treatment

Distribution system (quality, pressure, and continuity)

Quality control (records, sampling, tests)

Cross-connexion and back-siphonage control

Chlorine residual in the distribution system (where appropriate)

Construction and repair practices (including disinfection before services are resumed)

Maintenance procedures

Standard of operation

Table 1. Common failures of water surveillance

1. 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
2. Lack of established surveillance policies and procedures
3. Failure to make sanitary surveys
4. Failure to collect samples of raw and delivered water
5. Failure to enforce correction of deficiencies and remedial measures
6. Failure of laboratories to notify waterworks of results of analyses
7. Inadequate approval programme for new sources
8. Failure to adopt and enforce drinking-water standards
9. Failure to protect watersheds, wells, and springs from surface contamination
10. Failure to maintain positive continuous hydraulic pressure throughout the distribution system
11. Failure to maintain a continuous chlorine residual in distribution systems
12. Inadequate or non-existent cross-connexion and back-siphonage control programmes
13. Lack of standard laboratory procedures
14. Failure to maintain plant records, e.g., residual chlorine levels
15. Failure to maintain surveillance records
16. Bacteriological samples taken from fixed locations unrepresentative of the distribution system
17. Failure to disinfect new construction and repair work
18. Lack of adequate legal authority
19. Inadequate budget and manpower
20. Inadequate numbers of personnel suitably trained and qualified
21. Inadequate laboratory facilities and support
22. Failure to promote adequate maintenance programmes

Surveillance is not merely finding out what is wrong and putting matters right, it includes undertaking remedial action to reduce or eliminate health hazards and advising on, assisting with, and stimulating improvements whenever possible. Surveillance also includes more general activities to promote the safety of water supplies—operator training and health education of the public in the prevention of water-borne enteric disease, for example. Although such activities may be carried out by another agency, the surveillance agency should cooperate and maintain an active interest in this work.

Because no regulatory agency can be present constantly, surveillance must be shared between the water-supplying and the surveillance agencies. The periodic checks made by the surveillance agency ensure that water producers are satisfactorily monitoring their own activities. The water utility is continually responsible for the quality and safety of the water it supplies. However, the surveillance agency, acting on behalf of the public health interests, is ultimately responsible for ensuring that all drinking-water under its jurisdiction is free from health hazards.

The long period (several years) required for planning, financing, designing, and constructing a major water supply project for a community frequently results in a diminished concern for water quality, and provisions for adequate standards of operation, maintenance, and surveillance are often neglected. Yet, paradoxically, a new water supply system can readily become an effective channel for widespread transmission of disease.

Table 1 summarizes some of the more common surveillance failures as determined in a recent multi-country survey. Many of these failures reflect lack of capital and human resources, but some are compounded by complacency and apathy on the part of water supply and surveillance authorities. Effective surveillance is, to a large extent, a matter of correct attitude.

There are no mysteries in surveillance. There are no "breakthroughs", "shortcuts", or new discoveries to be reported. There are some ideas to be gained from the experience, good and bad, of others. This monograph attempts to bring together under one cover a set of useful procedures for those responsible for the quality of water delivered to urban and rural communities, particularly in the developing countries.

Reasons for surveillance

Water and health

Authoritative estimates indicate that each year some 500 million people are affected by incapacitating water-borne or water-associated disease, and that as many as 10 million of these—about half of them infants—die (*1*). It is estimated that 25 % of the world's hospital beds are occupied because of unwholesome water (*2*). The illnesses include typhoid, cholera, infectious hepatitis, bacillary and amoebic dysenteries, and many varieties of gastrointestinal disease (*3, 4, 5*). The existence of potential health hazards associated with water supplies is related to the quality of water consumed. For example, water that contains no *Salmonella typhi* cannot transmit typhoid fever. The health implications of water-related parasitic diseases in water development schemes are discussed in a brochure produced by the Food and Agriculture Organization of the United Nations (FAO) in conjunction with WHO (*6*).

In documented epidemics of water-borne disease definite deficiencies in the water supply system were shown to exist during the time when disease was transmitted. Most often the deficiencies were unforeseen pollution of a previously safe source, use of polluted raw water without treatment, failure of treatment processes, or pollution of the distribution system, including cross-connexions. All of these are subject to control and correction through proper surveillance.

Protection of investment in water supply programmes

A global survey of community water supply carried out to assess the situation prevailing in 1970 indicates that in the rural areas of developing countries, where the vast majority of the populations live, over 85 % of the people do not have satisfactory access to reasonably uncontaminated water. Over 30 % of the urban population in these countries had no access to a piped water supply, either in their houses or even from public standposts (*7*). Of the urban population that had access to a piped water supply less than 50 % enjoyed a continuous service, the rest were served by an intermittent supply attended by public health hazards.

On the basis of this information the Twenty-fifth World Health Assembly in 1972 endorsed revised global targets for community water supplies in the developing countries to be attained in the Second United Nations Development Decade (1971–80). These are as follows:

— in urban areas 60 % of the population to be served by house connexions and the remaining 40 % by public standposts;

— in rural communities 25 % of the population to have reasonable access to safe water (*8*).

The Health Assembly recommended that Member States adopt specific national targets for both urban and rural water supplies (*9*). The global construction costs to meet these targets were estimated at roughly US $14 000 million at 1970 prices.

The Twenty-fifth World Health Assembly also recommended that Member States "provide for the effective surveillance of drinking-water quality (*9*)".

Purpose of the monograph

The purpose of this monograph is to provide assistance to those countries, organizations, and persons who seek to prevent water-borne, enteric diseases by ensuring the safety of drinking-water supplied within their areas of jurisdiction.

Objectives of the monograph

The principal objective of the monograph is to provide information and guidelines for the development of national, state, or provincial water supply surveillance programmes and priorities at levels compatible with local resources and experience.

Other objectives are:

(*a*) to serve as a guide for surveillance organizations in evaluating their own programmes;

(*b*) to serve as a guide for national health organizations in evaluating the level of drinking-water surveillance being undertaken in their country;

(*c*) to provide a resource document for developing training curricula for surveillance and operating personnel; and

(*d*) to provide a check list to identify deficiencies in surveillance and waterworks procedures and possible remedial measures.

The monograph is also intended to show (1) that successful surveillance requires the joint efforts of both water supply and surveillance authorities and personnel, and (2) that surveillance requires an awareness of potential health hazards.

Scope of the monograph

This monograph is concerned only with operational activities that are of direct use in conventional surveillance programmes in developing countries. While proper management, planning, design, financing, operation, and maintenance of public water supplies are all essential for successfully providing safe water free from health risk, these areas are reviewed only when they relate directly to surveillance activities. Detailed procedures for bacteriological, chemical, and physical examination of water are widely available in the technical literature, and, with the exception of certain key determinations, are not repeated here. Similarly, the rationale for setting limits on particular constituents in drinking-water has been discussed elsewhere including, for example, *International standards for drinking-water* (*10*).

Limitations of the monograph

The broad purpose, objectives, scope, and intended readership place certain limitations of this monograph.

(*a*) The guidelines are necessarily of a general character and local use may call for appropriate adaptation.

(*b*) The policies and procedures outlined follow generally accepted practices in environmental health but are neither exclusive nor exhaustive; local initiative, knowledge, and innovation are not excluded.

(*c*) The monograph is primarily concerned with community water services rather than with systems serving dwelling units occupied by a single family.

(*d*) Surveillance in itself does not ensure a good water service but is only one essential element in the overall structure of public water supplies. For surveillance to be effective, the entire system must function properly—thus, proper management, design, construction, operation, and maintenance are vital in supplying safe drinking-water; these aspects are not covered in depth in this monograph but are dealt with in other WHO publications (see Preface, p. 10).[a]

(*e*) The monograph deals only with tangible aspects of surveillance although a characteristic of successful surveillance programmes is leadership—an intangible aspect: the role and importance of surveillance in water supply programmes is stressed here but surveillance is of limited value without strong, competent leadership.

(*f*) More than one approach to the development and operation of a sound surveillance programme is possible; in the final analysis, the surveillance programme must be viewed in the light of the results being obtained.

Levels of surveillance

The levels of surveillance of drinking-water quality differ widely in the developing countries, just as the levels of economic development and the provision of community water supplies vary. The scarcity of resources in these countries suggests the need to develop surveillance programmes by stages or "levels". A country with one sanitary engi-

Table 2. Programmes for surveillance of drinking-water quality characterized by the level or intensity of activities

Level of surveillance	Brief description	Country situation
I	Initial	Programme proposed for adoption in developing countries that at present have no formulated surveillance programme or responsibility
II	Basic	Programme proposed for adoption in developing countries that at present have a nominal programme with severe limitations on its scope and effectiveness
III	Interim	Programme proposed for adoption in developing countries that at present have an established programme in major cities only
IV	Intermediate	Programme proposed for adoption in developing countries that at present have an established, nationwide programme and seek to increase the effectiveness of surveillance
V	Advanced	Programme similar to those in use in developed countries that have generally eliminated water-borne diseases in community water supplies (This monograph emphasizes levels I–IV)

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[a] Other WHO publications that may usefully be consulted include: *Community wastewater collection and disposal* (*49*) and WHO Technical Report Series No. 420 (*4*), No. 490 (*13*), and No. 541 (*5*).

Table 3. Summary of principal activities for different levels of surveillance[a]

Activity by the surveillance organization	Level of surveillance			
	I	II	III	IV
1. Laws, regulations & policies	basic	basic	intermediate	complete
2. Enforcement		as needed for above		
3. Drinking-water standards	bacterial only	bacterial and physical	bacterial and physical, some chemical	international or equivalent
4. Technical assistance	limited	passive	special cases	active
5. Training:				
Staff	in-service	in-service + short course	in-service + short course	in-service + technical institute
Waterworks operators	none	seminars	seminars + short courses	seminars + technical institute
6. Sanitary surveys	major cities	all cities	all urban areas, some rural areas	all urban areas, many rural areas
7. Approval of sources		as above		
8. Sampling and monitoring	as above	as above	urban areas	urban areas, special rural areas
9. Standard methods of analysis	bacterial, residual Cl^-	bacterial, physical, and residual Cl^-	bacterial, physical, and some chemical	international or equivalent
10. Reporting requirements		for activities 6, 7, 8, 9		
11. Remedial action		as needed		
12. Establishment of laboratories	use existing facilities, e.g., health laboratory	specialized central laboratory	regional laboratories if needed	regional laboratories + fully equipped reference laboratory
13. Design standards or criteria	advisory	advisory	informal	formal approval

[a] For further details, see Annex 1.

Table 3 *(continued)*

Activity by the surveillance organization	Level of surveillance			
	I	II	III	IV
14. Control of cross-connexions	none	none	advisory	active programme
15. Plumbing code	none	none	advisory	codified
16. Laboratory support services	none	none	media + reagents should be available	evaluate laboratories at large plants
17. Materials and additives standards	none	none	advisory	approved listing
18. Regulation of special water supplies:				
Institutional	hospitals, major rail and air terminals	schools as for level I + army posts, prisons	as for level II + major housing projects	as for level III + other population concentrations
Temporary	none	large camps	fairs, markets	as above
Tanker	major cities	all cities	urban areas	all urban areas, some rural areas
Bottled water	none	none	large commercial bottlers	all commercial bottlers
Ice	none	none	large commercial manufacturers	all commercial manufacturers

neer per 5 million persons is hardly being realistic if it adopts a surveillance programme patterned on that of an industrialized country. The predictable failure of such programmes to meet their own stated performance standards gives rise to apathy and even cynicism.

A more realistic and pragmatic approach is to develop a surveillance programme adapted to the locally existing situation and economic resources of the country, to implement and consolidate the programme, and subsequently to develop by stages the ultimately desired level of surveillance.

Table 2 shows five levels or stages of surveillance programmes ranging from an initial programme, level I, proposed for those countries that at present have no formulated surveillance programme, to a complete programme, level V, similar to those in use in countries that have virtually eliminated water-borne disease associated with community water supplies.

Table 3 summarizes the activities appropriate to each level of surveillance (excluding level V). It is obviously not possible for this table to cover all situations, but the concept should be clear: determine the level of surveillance now existing, formulate the surveillance programme, meet the performance level specified, then move on to the next higher surveillance level. This process is repeated until the ultimate goal is achieved.

The highest level of surveillance consistent with available monetary, manpower, and material resources should be adopted initially and implemented.

In sections of this monograph covering surveillance activities the performance level associated with each activity is outlined in more detail.

2. *Organization*

The surveillance agency

The surveillance agency must provide the professional services necessary to fulfill its responsibilities of ensuring that the health of the public is protected. Most of the developing countries lack fully adequate community water supplies and drinking-water surveillance programmes (*7*). In most instances a substantial expansion is needed to meet the needs for trained personnel, laboratory facilities, and the other resources necessary for conducting an effective surveillance programme. The establishment, operation, and management of surveillance agencies are discussed in this chapter, but the discussion is restricted to aspects directly related to drinking-water surveillance functions. General information on environmental health administration may be found in some other WHO publications (*4, 5, 11, 12*).

Dual responsibilities of waterworks and health authorities

Surveillance agencies and waterworks are not in competition with one another but are, rather, complementary. Proper utilization of available resources by each body permits a more complete public service to be provided, usually at less cost.

Combining the water production and surveillance functions in a single agency is sometimes proposed, and examples exist especially in rural areas. However, long experience in many countries indicates that human weaknesses often limit the effectiveness of such arrangements. Awareness that all activities, whether a sanitary survey or an audit of the financial records, are subject to external review discourages the development of complacency and promotes improved performance and greater awareness of the need for surveillance. The standards of operation of certain large, complex, and well-run city water supply agencies having their own qualified staff and laboratory services may be so high that the surveillance duties of the health authorities can be reduced to a minimum. In such instances the surveillance agency, while retaining its ultimate responsibility for ensuring the safety of all public water supplies, will be able to give more of its attention to supply systems with poorer internal surveillance. For example, in small, remote, 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. Even in areas without public water supplies the surveillance agency may be able to reduce the grosser hazards of water-borne epidemics through advice and technical assistance.

In any event, both the water-producing and surveillance agencies must undertake essential surveillance activities. To repeat the analogy used in the preceding paragraph, the external auditor of the waterworks accounts does not enter every debit or asset as it occurs, and the surveillance agency does not take and test every sample. Rather, the agency provides supervision and makes spot checks of the waterworks' performance.

Certain characteristics of surveillance indicate the desirability, if not the necessity, of assigning surveillance responsibilities to a separate agency, usually the health ministry.

(1) Surveillance of drinking-water quality is essentially a health measure, the primary purpose of which is to protect the public from water-borne diseases. As such, health authorities have a unique capability for providing surveillance.

(2) As a health measure, surveillance should be integrated with other environmental health measures, especially sanitation.

(3) Surveillance is a specialist subject requiring special knowledge and personnel experienced in health matters, particularly sanitary engineers, sanitarians, epidemiologists, chemists, biologists and others, with support from the medical profession, especially during outbreaks of enteric diseases such as cholera. Few water systems can afford their own full-time cadres of such personnel.

(4) Surveillance is most effective when it enjoys informed public support through introduction of the concept into health education and other public health programmes.

(5) Centralization of certain surveillance activities such as laboratories and training programmes, which may already exist within health ministries, can result in considerable economies.

(6) The need for reporting periodically to the government on the public health aspects of water supplies in the country.

Administrative organization

No single pattern of organization can, or should, be applied universally. A wide variety of administrative arrangements exist and are likely to continue in use since political structures, demographic patterns, economic development, level of water supply services, legal systems, and governmental practices differ from country to country. The real criterion is whether the organization provides effective surveillance. A corollary is, if surveillance is not being provided is it owing to the organizational structure or is there some other reason? Effective leadership, adequate resources, and legal delegation of authority and responsibility are more important than organizational structure.

Inauguration or strengthening of a surveillance programme should not await the development of an ideal organizational structure. All too often new situations are met by reorganization, which may create an illusion of progress while producing confusion and inefficiency.

In small countries, or very large countries with a highly centralized administration and a small number of professionally qualified or potential personnel, national programmes may have special merit. When the surveillance organization is under a ministry of, say, health, it may be desirable to organize subunits on a local, regional, state, or provincial basis in parallel with those in the parent ministry. In some countries, for example, sanitarians employed in rural drinking-water quality surveillance have worked effectively from regional health divisions.

Levels of surveillance

The many differences that exist between countries have been mentioned in the previous section. Similarly, there are great variations in the levels or stages of surveillance programmes that can be established and sustained during the next few years in the various countries.

A common weakness found in a recent multi-country survey of national surveillance programmes was their failure to adopt formal, realistic programmes with stated, quantifiable goals and objectives that could be achieved under local conditions. This monograph advocates the following steps in establishing appropriate levels of surveillance.

(1) Formally review the existing surveillance programme, its resources, authority, performance, objectives, and criteria, and summarize the status of the current programme.

(2) Survey the needs of the country with regard to water quality surveillance, making an inventory of the number of water supply systems and their distribution according to size and noting the existing level of surveillance by waterworks operators and the prevalence of water-borne diseases.

(3) Having determined the current level of surveillance by comparing step 1 with Tables 2 and 3 (it is unlikely that they will correspond exactly; it is the concept of stage-wise development that is important), select the next higher level of surveillance as an intermediate goal.

(4) Compare step 3 with step 2, outline a formal programme, and estimate the budget, manpower, and time that will be needed to establish the new level of surveillance. It may be necessary to balance the time required to establish the improved surveillance level against the resources available, i.e., if the budget or manpower resources are insufficient for meeting the target date it will be necessary to provide more funds or extend the time.

(5) Adopt the new programme, establish formal objectives, and report on progress every year. Some examples of formal objectives are:

(*a*) to apply the international standards for drinking-water (*10*) to all community water supply systems serving a population of, say, 50 000 or more within a specified period—10 years, for example;

(*b*) to make periodic sanitary surveys of all new water sources serving a population of, say, 500 or more by a specified date;

(*c*) to provide training for 1 week or more each year for a significant number of full-time waterworks personnel.

These objectives can be costed and progress measured quantitatively against the targets reached.

(6) When a higher level of surveillance has been established repeat the process, moving to the next surveillance level.

Tables 2 and 3 give urban areas priority over rural areas in surveillance activities. This is realistic because it is the usual pattern and also because to achieve maximum cost-effectiveness (i.e., return per unit of resource invested) surveillance priorities should maximize the expected benefit, which is a product of the population at risk multiplied by the reduction in the probability of the risk. Thus, favoured situations are large populations served by surveillance activities with a high potential for risk reduction—large populations using approved raw water sources, for example.

Assessment of the existing situation

Water supply systems vary greatly in size, ranging from small systems serving individual families to systems serving millions of consumers. Even in the wealthier countries, manpower and financial limitations prohibit full surveillance, and agencies give more attention to the larger systems because (1) the risk of water-borne epidemics increases with the size of the system; (2) more people can be protected with a given surveillance budget (i.e., the unit cost of surveillance is lower);

(3) larger systems more often than smaller ones take water from poorer quality raw water sources (e.g., rivers rather than drilled wells); (4) in densely populated areas the hazards of contamination are greater; (5) large water systems have access to laboratory facilities and skilled manpower; (6) stronger, more effective organizational support is available in urban areas; and (7) it is traditional to do so.

In choosing the systems to be included in a routine surveillance programme, the practice of one state 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 represented 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 smaller 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.

Because a water supply system may be smaller than the "community water supply" as defined by the agency does not mean that it can or should be ignored, but the focus of effort will differ, more emphasis being given to health education and community demonstration than to routine laboratory analyses, for example. In special circumstances such as a cholera outbreak the entire range of surveillance activities—sanitary surveys, sampling, laboratory analyses, etc.—should be extended to even the smaller systems. Generally, however, when resources are limited more emphasis should be given to surveillance of larger systems.

In addition to water systems serving resident populations, systems for restaurants, hotels, parks, sea ports, airports, railway stations, fairs,[a] centres of pilgrimage, festivals, military camps, and other concentrations of transient populations should receive particular attention because of their potential role in disease transmission.

In carrying out the "census" of water systems, other highly useful in-

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[a] Fairs in India have attracted as many as 3 000 000 people in the course of a single day.

formation can be gathered at marginal cost; this includes data on operators, laboratories, planned expansions, water consumption (when records exist), water sources, etc. Guidelines for data collection are presented in the report of a WHO Scientific Group on techniques for the collection and reporting of data on community water supply (*13*).

Estimating manpower and budget requirements for surveillance programmes

This section offers some guidance on the preparation of manpower and budget estimates for expanded surveillance programmes by centralized agencies such as state or provincial health ministries or departments. The process must generally be repeated several times in order to adjust the programme to the limitations of resources and available data. Adjustments can be made by limiting full surveillance to systems of a certain minimum size (see previous section), by redefining the scope of surveillance (the frequency of sanitary surveys, for example), and by reassessing priorities. Further refinements might include separating water systems according to source—groundwater or surface water—and grouping systems by size.

Data needed include an inventory of systems under surveillance; unit time estimates (man-days or man-hours) for sanitary surveys and bacteriological and chemical analyses; pay rates for various categories of personnel; and overhead costs. Surveillance policies and procedures must also be defined—frequency of surveys and sampling, parameters to be analysed, etc. In some systems initial estimates may be quite crude, but the process, if continued annually, also identifies the data and records needed and estimates should therefore improve with time.

An inventory of water systems by size is the first step. Following the procedure outlined in the preceding section, the systems to be surveyed are identified—say, all those serving over 1000 people. If it is not feasible to provide the total budget requirement, systems serving over, say, 5000 people might be routinely surveyed and the small systems surveyed only on an *ad hoc* basis. As more resources become available the minimum population supplied might be reduced in future years to include smaller systems.

The average man-day requirement for sanitary surveys and related technical assistance, including plan reviews, meetings with governing bodies, report writing, informal in-service training, etc., must be estimated from agency records. Also required are costs of salaries, fringe benefits, travel, secretarial support, etc.

Written procedures

Many surveillance agencies find written guidance on agency organization, objectives, policies, and procedures useful. While surveillance activities require judgement rather than unquestioned uniformity, many activities benefit from uniform systems including data collecting, laboratory analysis, and record keeping. An example of such a written procedure is the enforcement operation manual outlined in Chapter 8.

Independent budget

Independence of action is directly related to financial independence. A common characteristic of all effective surveillance agencies is their relative independence in budgeting. Surveillance agencies are sometimes forced to take certain actions that may be unpopular, but when things are going well the public is usually unaware of the agency's activities. The effectiveness of the surveillance may, however, be taken (erroneously) as a sign that less surveillance (and a smaller budget) is justified.

Supporting services

The availability of supporting services such as transport and communications is essential to proper surveillance. The nature of the activity often demands immediate response. Adequate clerical support is needed for record-keeping.

3. *Laws, regulations, and standards*

Legislative authority

Appropriate legislation, regulations, and policies are basic to the development of effective drinking-water surveillance programmes. The basic legislation, statute, or code should specify:

(1) the scope of authority, including authority over all drinking-water within the jurisdiction of the agency;

(2) the agency or agencies delegated to administer the law;

(3) the right of the agency to establish, amend, and enforce regulations and bylaws for the development, production, distribution, and protection of safe drinking-water.

Suprisingly, many countries lack such basic legislation (*7*) and much existing legislation is seriously out of date. However, development of a surveillance programme *should not wait* for the enactment of legislation, which may take several years. Much can be done under general welfare or health legislation and with voluntary cooperation.

Provisions for compliance

The statute or statutes should provide for compliance with all laws, rules, regulations and policies and include appropriate sanctions for noncompliance. Although the surveillance authority should ideally be capable of achieving its objectives through counselling and cooperation rather than through law enforcement, it will almost certainly be necessary on occasion to use legal sanctions against an individual or organization in the public interest. While such powers should be used sparingly, they should be available for immediate use during an emergency.

Financial incentives

Provision of financial incentives such as government subsidies or grants to waterworks may be more effective in improving drinking-water quality than application of legal sanctions against the supply agency. If the surveillance agency is not authorized to approve subsidies it should advise the approving body.

Drinking-water standards

The surveillance agency should be empowered to enforce quality standards for drinking-water adopted by the country, generally by the health ministry. Considerable scientific and medical judgement and experience beyond the capacity of most water treatment plant operators is necessary for determining whether water is wholesome. The international standards for drinking-water (*10*) have been adopted widely (*7*). Some countries have adopted international or national standards in whole or in part. Others have modified these standards or have established their own standards. Evaluation of the source and specification of methods of laboratory analysis are integral parts of drinking-water standards.

Codes for water distribution and plumbing

Incorrect plumbing practices and use of unsatisfactory fixtures have resulted in numerous outbreaks of water-borne disease. The surveillance agency should work closely with national standards organizations, health ministries, manufacturers, trade associations, waterworks, training institutions, and others bodies to promote safe plumbing.

Other standards

In countries having no national standards organization, surveillance agencies may wish to promote standards for waterworks equipment, materials, and practices. These standards can relate to health directly (by forbidding the use of lead pipes in distribution and service networks, for example) or indirectly (by standardizing handpumps, for example, to simplify maintenance and repair and thereby increase service reliability).

Specific authority

Some of the surveillance activities that may be specifically authorized or delegated are as follows:

(1) approval of new water sources and methods of treatment;
(2) surveys, sampling, and laboratory analysis;
(3) protection of watersheds and reservoirs;
(4) disinfection;
(5) operator training and certification;
(6) codes for construction of wells and springs and installation of pumps;
(7) provision for central laboratory services;
(8) control of cross-connexions and back-siphonage;
(9) approval of construction plans where appropriate;
(10) surveillance of privately owned water supplies;
(11) approval of tanker supplies;
(12) surveillance of bottled water plants;
(13) surveillance of ice manufacture;
(14) rights of inspection and entry;
(15) technical advice and consultation;
(16) promotion of standards for waterworks equipment and chemicals.

Which of these activities are carried out will depend on the level of surveillance sought.

4. *Personnel*

Introduction

The professional disciplines most directly involved in drinking-water quality surveillance are engineering, sanitation science, and laboratory practice. Numbers of personnel will be proportional to the area of jurisdiction and the level of surveillance sought.

Since surveillance is an integral part of waterworks operation, the waterworks personnel as well as those of the surveillance agency will be involved in surveillance. Many of the personnel of the two bodies, laboratory staff, for example, will have similar duties and require similar qualifications.

In the developing countries both water production and surveillance organizations often have inadequate resources, including those of funds, skilled manpower, materials, transport, laboratory facilities, and public support. Careful consideration of the duties, qualifications, and training of staff is therefore most important. Personnel requirements must be determined by circumstances.

Surveillance agency staff

The surveillance agency should estimate its manpower requirements in accordance with the methods outlined in Chapter 2. Manpower requirements should be summarized in terms of positions to be filled, numbers of personnel needed and qualifications necessary, duties to be carried out, and in-service training required. The specimen summary given in Table 4 is based on the experience of a West African water authority serving a population of around 5 million in an area of about 780 000 km^2.

Table 4. Surveillance agency personnel; specimen summary[a]

Job title (and numbers)	Qualifications	Duties	Training
Principal health superintendent (1)	(*a*) a school-leaving certificate (*b*) a recognized diploma as public health inspector (*c*) a diploma in environmental sanitation (*d*) overseas training in public health engineering (*e*) minimum of 15 years' experience	(*a*) heads the surveillance programme (*b*) coordinates surveillance activities (*c*) responsible for staff training	specified courses such as environmental control and environmental sanitation
Senior health superintendent (SHS) (8)	as above, with minimum of 12 years' experience	(*a*) responsible for surveillance activities in his district (*b*) carries out regular sanitary surveys	specified courses such as environmental control and environmental sanitation
Higher health superintendent (7)	As above, but 9 years' experience	assists the SHS in carrying out above duties	specified courses such as environmental control and environmental sanitation
Health superintendent (HS) (10)	6 years' experience as public health inspector	a health superintendent or an assistant health superintendent is in charge of water surveillance activities in his division	specified courses such as environmental control and environmental sanitation

[a] This table is intended only as an illustration and is not necessarily a recommended list of personnel. Such lists must be established in accordance with local conditions, resources, and levels or goals of surveillance.

Table 4 *(continued)*

Job title (and numbers)	Qualifications	Duties	Training
Assistant health superintendent (AHS) (18)	3 years' experience as a public health inspector	a health superintendent or an assistant health superintendent is in charge of water surveillance activities in his division	specified courses such as environmental control and environmental sanitation
Public health inspector (223)	*(a)* a school-leaving certificate *(b)* a recognized diploma as public health inspector	undertakes water sampling for bacteriological and residual chlorine testing, carries out residual chlorine analysis, and sanitary surveys	3 years' training at a school of hygiene to obtain a public health inspectors diploma
Laboratory staff:			
Chemist (1)	university graduate in chemistry (must have a knowledge of microbiology)	heads the laboratory and supervises all bacteriological and chemical analyses of water	special courses such as membrane filter analysis
Laboratory technician (2)	a school-leaving certificate plus 2 years' training in microbiology	assists the chemist	joint short courses with waterworks laboratory personnel

Chief of the surveillance programme

Ideally, it is desirable that the programme should be headed by an experienced sanitary engineer or scientist with executive ability and professional skills in waterworks operation and environmental health protection. He should have good professional standing and be respected by the local community.

Sanitarians

The backbone of the surveillance programme is the corps of sanitarians or public health inspectors and their assistants. Although personnel with a formal, institutional training are desirable they are by no means essential. Successful surveillance programmes have been undertaken, mainly in smaller communities, by personnel with a limited education (in-service training and intensive short courses) working under close, qualified supervision and equipped with clear, comprehensive instructions.

Waterworks staff

Although not employed by the surveillance agency, these personnel have a key role in maintaining drinking-water quality. The surveillance agency must therefore strongly promote suitable training for waterworks staff.

Technical director

Directors of technical operations of large water supply systems serving metropolitan or regional areas should have received an appropriate education in engineering or science and have experience of plant operation.

Plant operators

Operators should be good managers and they should be familiar with hydraulic principles as applied to waterworks operation. These personnel should know and recognize public health hazards in water production, treatment, and distribution; be acquainted with waterworks safety practices; and be able to perform or supervise physical, chemical, and bacteriological tests and to interpret the results of these tests in order to assure proper operation of the plant. In addition, operators should be familiar with the national drinking-water standards and be able to manage plant equipment and personnel to maintain these standards continuously.

Other staff

A water plant also requires adequate numbers of competent assistant operators, laboratory workers, and maintenance personnel. The staff should be sufficient for all circumstances, including holidays, illnesses, or emergencies.

Lack of manpower and other resources makes it difficult in some developing countries to obtain suitably qualified and experienced staff to operate waterworks. Experience has shown that trained and responsible subprofessional staff (waterworks superintendents) adequately supported by trained operators and other skilled personnel, many of whom have been trained in service, can reasonably operate waterworks supplying populations of up to half a million people. An arrangement found satisfactory in some cases is to create waterworks districts with a competent engineer as supervising officer, each waterworks being looked after by the waterworks superintendent.

Senior officials of public health organizations

Whether the surveillance agency is independent or comes under a health ministry, cooperation, coordination, and support of the health infrastructure within the agency's area of jurisdiction are essential for obtaining public understanding of, and support for, the surveillance programme and ensuring its effectiveness. In emergencies and crises, which often face water supply programmes in the developing countries, a well established working liaison with senior health officials is important, especially in rural areas where water surveillance and health activities may overlap.

Medical examination of operators

No person thought to be suffering from a water-borne disease, or who might be a carrier of such a disease, should be allowed to come into contact with drinking-water at any stage of its treatment or distribution or with any surface that could convey contamination to the water supply. Medical examination of all waterworks employees is particularly important when an epidemic breaks out or appears likely. Anyone suffering from diarrhoea or open sores who could contaminate the water in the course of his duties should be sent home or given other work until he is fully recovered. This applies not only to regular staff but also to casual labour engaged in cleaning reservoirs or walls, handling pipes or other equipment, making repairs, etc. Close liaison between the waterworks management and the medical authorities is essential when work is undertaken by outside contractors or labour.

Owing to the acute nature of cholera, blood tests or bacteriological examination of stools for *Vibrio cholerae* are of little practical use for screening infected waterworks staff. Therefore, reliance must be placed upon excluding anyone suffering from diarrhoea or exhibiting other symptoms that could indicate infection. Relatives and other persons in close contact with cholera patients should also be kept away from water installations.

Tests for carriers of typhoid or paratyphoid are outlined in Annex 2.

Training programme

Competent personnel are needed for the distribution and effective surveillance of drinking-water supplies. The surveillance agency should support the establishment of appropriate educational training in local universities and other technical institutions. When such training is not available locally senior staff should take advantage of educational programmes in other countries, especially at the postgraduate level. Intermediate-level staff can, with advantage, be attached for short periods to waterworks at home or abroad. However, only limited numbers of personnel will be able to participate in such programmes. The need to train larger numbers of staff, especially junior staff, at the local level on existing equipment and in their own language means that if no local educational or professional organization fills the need, then the surveillance agency must do so. The economy of hiring a qualified instructor to teach students at home rather than sending students long distances to receive instruction should not be overlooked.

Training is expensive and should not be wasted by failure to provide adequate financial incentives to retain trained personnel or by the diversion of trained staff to assignments unrelated to their training.

The parallel training requirements for staff of waterworks and surveillance agencies indicate the usefulness of jointly operated training programmes utilizing the best laboratory facilities and manpower and other resources of both types of agency.

Training courses

Details of courses on sanitary surveys, membrane-filter bacteriological sampling and testing, control of cross-connexions, and operation of water treatment plants are given in Annex 6. An example outline curriculum is given for each course with suggested timing and duration of lectures, demonstrations, laboratory sessions, and field trips, together with references to technical literature for each lecture.

5. *Sanitary surveys*

Introduction

The *sanitary survey* is an on-the-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 wellbeing 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, as outlined in this chapter.

Depending on the resources available, the sanitary survey may or may not include sampling and laboratory analysis, which are useful but not essential. On the other hand, a sanitary survey is indispensable for adequate interpretation of laboratory results. No bacteriological or chemical survey, however carefully it is made, is a substitute for a complete knowledge of conditions at the source and within the distribution system, the adequacy of the water treatment, and the qualifications and performance of the operators. Samples represent a single point in time, and even when samples are taken and analysed frequently reports are made after contamination has occurred, especially in systems without long-term storage. Contamination is often random and intermittent, and is not revealed by occasional sampling. For example, during a major outbreak of infective hepatitis (a virus infection) in Delhi, India, bacteriological samples gave "satisfactory" results throughout the period (*14*).

Sanitary surveys are fact-finding activities that should reveal system deficiencies, not only sources of actual contamination but also inadequacies in the system that could result in failure to control contamination should it occur. Furthermore, the survey report should advise water supply operators or managers on ways to eliminate defects and improve water quality. In this regard many reviewing authorities have found it helpful to have a responsible person from the waterworks present during the survey to acknowledge the findings by signing a receipt for the survey report.

Every water supply system should be surveyed periodically by a separate, external agency, preferably one that is knowledgeable about both water supply technology and its implications for health and disease transmission. Although it is unrealistic in most instances to expect the surveillance agency to devote more than 1 or 2 days each year to a survey, this can hardly be considered an adequate programme. Thus, sanitary surveys should be undertaken periodically by waterworks personnel as well as by the surveillance agency.

Many potential hazards can be detected by a sanitary survey of the water source and the treatment and distribution facilities. The detection and correction of faults and deficiences is the main purpose of the sanitary survey.

Timing and frequency of surveys

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

New sources

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 to supply smaller systems and of well waters 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.

Possible contamination

Another important survey, and the most urgent, is that undertaken when laboratory analyses of a sample taken from the water system or complaints from consumers indicate the possibility of contamination. A survey should be started immediately to identify the source of contamination. Attention should be given first to the most common causes of contamination (see Annex 4). In systems using chlorination treatment, residual chlorine levels should be checked immediately and chlorination equipment and records examined.

Epidemics

A sanitary survey similar to that made when there is a possibility of contamination should be undertaken if or when epidemiological evidence indicates an outbreak of water-borne disease in or near the area served by the water supply system. This survey should be undertaken even though laboratory records indicate that the water samples analysed are of a satisfactory quality. Contamination of water supplies is often sporadic and undetected by intermittent sampling. During epidemics the sanitary survey should not be limited to the piped public water supply but be extended to all water sources in the community.

Interpretation of laboratory analyses

A sanitary survey is required for interpreting bacteriological, chemical, and physical analyses of water samples taken from a water supply system. These surveys are most useful when (1), as previously noted, contamination is suspected; (2) significant changes from the normal occur, e.g., when the water is higly turbid owing to flood conditions; and (3) when sampling is infrequent. These surveys may or may not be complete, depending on the seriousness of the circumstances.

Significant changes

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.

Regular sanitary surveys

The frequency and timing of regular sanitary surveys will depend on the size of the water supply system, whether maintenance is efficient, susceptibility to contamination and interruption of services, and the staff

Table 5. Illustrative programme guidelines for regular sanitary surveys by surveillance agencies[a]

Level of surveillance programme	Population water system under survey	Source						Treatment								Distribution and storage	
		Groundwater			Surface water			Groundwater				Surface water					
		New	Existing		New	Existing		Chlorinated		Unchlorinated		Chlorinated		Unchlorinated			
		Sanit surv.[b]	Sanit surv.[b]	Freq.[c]	Sanit. surv.[b]	Sanit. surv.[b]	Freq.[c]	Sanit. surv.[b]	Freq.[c]	Sanit. surv.[b]	Freq.[c]	Sanit. surv.[b]	Freq.[c]	Sanit. surv.[b]	Freq.[c]	Sanit. surv.[b]	Freq.[c]
I	Rural areas	no	no		no	no	—	no	—	no	—	no	—	no	—	no	—
	Towns	no	no		yes	no	—	no	—	no	—	no	—	no	—	no	—
	Cities	yes	yes	3 years	yes	yes	2 years	yes	3 years	yes	3 years	yes	2 years	yes	1 year	yes	3 years
	Major cities	yes	yes	2 years	yes	yes	1 year	yes	2 years	yes	2 years	yes	1 year	yes	1 year	yes	1 year
II	Rural areas	no	no	—	no	no	—	no	—	no	—	no	—	no	—	no	—
	Towns	no	no	—	yes	yes	3 years	no	—	no	—	yes	3 years	yes	3 years	no	—
	Cities	yes	yes	3 years	yes	yes	1 year	yes	3 years	yes	3 years	yes	2 years	yes	2 years	yes	2 years
	Major cities	yes	yes	2 years	yes	yes	1 year	yes	2 years	yes	2 years	yes	1 year	yes	1 year	yes	1 year
III	Rural areas[d]	part.	part.	irreg.	part.	part.	irreg.	no	—	no	—	no	—	no	—	no	—
	Towns	yes	yes	5 years	yes	yes	3 years	yes	5 years	yes	5 years	yes	3 years	yes	3 years	yes	5 years
	Cities	yes	yes	3 years	yes	yes	2 years	yes	3 years	yes	1 year	yes	1 year	yes	1 year	yes	2 years
	Major cities	yes	yes	2 years	yes	yes	1 year	yes	2 years	yes	1 year	yes	1 year	yes	6 months	yes	1 year
IV	Rural areas[d]	part.	part.	irreg.	part.	part.	irreg.	part.	irreg.	part	irreg.	part.	irreg.	part.	irreg.	part.	irreg.
	Towns	yes	yes	3 years	yes	yes	2 years	yes	3 years	yes	3 years	yes	3 years	yes	2 years	yes	2 years
	Cities	yes	yes	1 year	yes	yes	1 year	yes	1 year	yes	1 year	yes	1 year	yes	6 months	yes	1 year
	Major cities	yes	yes	1 year	yes	yes	6 months	yes	1 year	yes	6 months	yes	6 months	yes	3 months	yes	6 months

[a] Surveillance levels, populations, sanitary surveys, and survey frequencies shown in this table are for purposes of illustration only and must be considered in conjunction with the text. Surveillance programmes must be suited to the resources and needs of particular countries. The table illustrates how a framework plan for sanitary surveys can be developed by stages or levels, and a programme for long-term improvement planned by moving to a higher (down the table) level as each level of surveillance is achieved and consolidated.

[b] Sanit. surv., sanitary survey.

[c] Freq., frequency, i.e., 1 survey per given number of years or months.

[d] irreg., irregular frequency; part, partial coverage.

and resources available. Treatment plant operators should make their own regular sanitary surveys, and these surveys should be noted in the plants' log-book. The surveillance agency also should undertake sanitary surveys on a regular basis, ideally at least once a year. Large systems should be inspected more frequently because of the size of the population served, variability in the quality of their water sources, and greater cost-effectiveness of surveillance. The smaller systems should also be surveyed, but the frequency should be based on experience of what can be achieved with the available manpower. A rural country with only one sanitary engineer for a population of 5 million may have to forego temporarily direct control of water supply systems serving fewer than a specified number of consumers. Even here, however, group training of operators and sanitary aides in sanitary surveys can be useful.

Table 5 presents illustrative survey schedules for various levels of surveillance programme, as previously defined and described in Tables 2 and 3. The sizes of water systems (i.e., population served) are indicated only in qualitative terms but they can be defined quantitatively using the procedure outlined previously. The survey schedule must, of course, be adjusted to water supply programmes, manpower and budgetary resources, demographic conditions, transportation networks, past history of contamination and interruptions of service, and other relevant factors in the particular country or region. The schedules proposed in Table 5 are postulated as reasonable minimum objectives, and the formal development of programme and planning criteria, as illustrated by the table, should be undertaken in any event.

Rural areas present a special problem for sanitary surveys—namely, the physical and economic impossibility of surveying the innumerable small water suppliers. Efforts by surveillance agencies must primarily encourage and stimulate individuals and community groups to make their own improvements, provide information on proven techniques, and give technical assistance for site selection, design, and construction. Demonstration of proper practice, rather than condemnation of the improper, should be aimed at. Annex 4 offers some technical guidance on these matters.

Qualifications of sanitary surveyors

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 would 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 programme director should possess these qualifications and should have received formal training in sanitary engineering or science.

Routine external surveillance is generally provided by sanitarians and public health inspectors who are not fully trained in the engineering disciplines related to water supply facilities. Technical assistance should be available to the inspectors if needed. Larger or more complex systems should be surveyed by senior personnel.

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 programmes. Technical assistance and fellowships are available through WHO and other international bodies.

Experience shows that successful surveillance programmes can be operated by secondary school graduates with 1–2 years' technical instruction and in-service training and experience, provided they are closely supervised by qualified personnel.

Personal characteristics of sanitary surveyors are also important. Maintenance of a professional attitude and approach is important in direct contacts with waterworks operators. If the surveyor goes about his task in a thorough, professional manner and makes comments, suggestions, and recommendations that will lead to improvements in the system, the surveillance agency, the water supply, and the community will all benefit from the survey.

The performance of the sanitary surveyor should also 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.

As previously indicated, the majority of routine sanitary surveys must be made by waterworks staff. In smaller water supply systems, especially, this necessitates additional operator training through short courses or certification programmes. A senior waterworks official should 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 (see below, p. 42).

Operators

A sanitary survey is intended to evaluate existing and potential health hazards in a water supply system. Even the finest and best equipped waterworks can give rise to health risks if they are operated incompetently. Conversely, the simplest works have produced water of good quality when well managed and operated. Review of the operator's qualifications is therefore a logical part of a survey. Unfortunately, operator evaluation is subjective and not readily expressed in quantifiable terms.

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.

Operators of water treatment plants should have had a secondary school education (or the equivalent) and training and experience in water supply technology. In some countries such requirements have legal authority, but this is possible only where health agencies, professional and other societies, educational institutions, or other bodies make such training available.

It cannot be overemphasized that a thorough, competent sanitary survey is an excellent opportunity for operator training and sometimes the only external training available for operators. In addition to explaining why various survey activities and treatment processes are necessary, survey personnel should demonstrate proper methods for selecting sampling points, taking of samples for bacterial and chemical analysis, and measuring residual chlorine.

Even though public water supply systems should not be criticized for having inadequately qualified operators (unless the criticism is supported by corroborating evidence such as repeated instances of water contamination), the survey report should record the numbers of full-time and part-time operators and, for principal operators, their education and experience, how long they have held a particular position, special training they have received, and other relevant information. Not only is such information useful in evaluating an individual water supply system, but when compiled for many systems it is useful in surveillance agency evaluations of manpower status and needs.

Sanitary survey report forms and records

Printed guidelines, checklists, and forms for recording sanitary surveys are of considerable value to both surveillance agency personnel and water supply system operators. Report forms are often drawn up in the national language and mimeographed on inexpensive paper. Several publications offer excellent guidance in this respect and some examples are given in Annexes 4 and 6.

In addition to their educational value and utility as checklists, such report forms become part of the permanent record and, as such, are useful for enforcement of quality standards and follow-up evaluations of corrections made. Some agencies have found it useful to require both the inspector and the principal waterworks operator to jointly initial the form. This not only serves as an acknowledgement that the report has been received, but also helps to ensure that the operator is aware of the deficiencies uncovered. The completed report form can be treated as the report, and copying is not necessary if carbon copies are made when the form is being completed. At least one copy should be retained by the surveillance agency and one given to the water supply management. Ample space should be provided for additional written comments.

The report must show clearly and unequivocally the recommendations made, actions that must be taken, and latest times for action. Confusion between "suggested" or "desirable" and mandatory action must be avoided.

Sanitary survey guidelines

Guidelines for sanitary surveys are presented in Annex 4. These are grouped by function—sources, treatment, distribution, and storage—and common sanitary defects. Problems of cross-connexions are discussed in Annex 5.

The guidelines are not comprehensive; any element of the water supply system that may allow faecal contamination of the water, and there are many possible routes, is a deficiency. The guidelines are intended as a checklist of the commoner sanitary deficiencies in water supplies and as a training aid.

The guidelines are also useful in reviewing designs and construction plans and specifications prior to construction. In some countries plans for major new construction work or extensions of existing constructions must be reviewed and approved by the water surveillance agency. This practice can be particularly valuable when designs are prepared by civil or hydraulic engineers with limited public health experience; however, these requirements will generally be applied only when surveillance programmes have enough experienced personnel to make meaningful reviews and simultaneously to carry out other activities with a higher priority—approval of water sources, sanitary surveys, training, and staff supervision.

An important requirement common to all elements of the water system is reliability, not only during normal operations but also during periods of unusual stress or emergency. Reliability is linked with proper maintenance and structural features designed for continuity of operation. Examples of the latter are provision of two or more wells for systems using groundwater sources, provision of standby power sources or elevated water storage, and installation of valves in the distribution system to permit partial shutdowns for repair work. Waterworks are susceptible to damage from earthquakes, floods, and other disasters. Useful guidance in the situations may be found in *Guide to sanitation in natural disasters* (*15*).

Records

Another important requirement for the entire waterworks system is to maintain proper records. Preparation for a sanitary survey of the system should include compilation and review of all records including those of flows, plant and distribution system operation, chemicals added, water quality at the plant and in the distribution system, operator training, and consumers' complaints. The surveyor should also review his own records of previous surveys, remedial action taken, if any, and outbreaks of water-borne enteric disease in the community served by the system.

6. *Sampling of drinking-water*

Introduction

This chapter deals with sampling by both waterworks and surveillance agency personnel. Tables 6, 7, and 8 show the respective timing and frequency of sampling by the two agencies.

Samples are taken from water systems in order to determine whether the water supplied is safe for human consumption, and they must therefore be representative of the water supply as a whole. If the sample is carelessly taken or is taken from locations that are not truly representative of the whole system, then the purpose of sampling is defeated. Unrepresentative sampling may even be dangerous if it gives rise to unjustified confidence in the quality of the water.

One sample taken from a water system is of limited value; long records and repeated sampling are desirable.

Bacteriological sampling; frequency and number

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 budgets 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 centres of pilgrimage, for example), and the practice of chlorination.

It might be thought that if chlorination is practised 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 is practised 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. Constant checking of chlorine residual concentrations and bacterial quality is therefore necessary to ensure that immediate remedial action is taken if water of doubtful quality enters the distribution system.

On account of the many variables outlined above, and the differences in resources available for surveillance, no universally applicable sampling frequency can be suggested. Ideally, bacteriological examinations of chlorinated water should be made daily. This is feasible for the largest supply systems but may be impracticable for the smaller systems, which may have to rely on weekly or monthly bacteriological analyses. The smallest supplies may have to rely completely on sanitary surveys and, if chlorination is practised, frequent determinations of residual chlorine concentrations.

Recommendations for sampling (numbers of samples and frequency of sampling) are to be found in *International standards for drinking-water* (*10*). 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 Table 6.

The number of samples taken and the frequency of sampling must be decided by the surveillance agency, taking local conditions into ac-

Table 6. Maximum intervals between successive samples of water entering the distribution system[a] and minimum number of samples to be taken

Population served	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	
50 000 - 100 000	4 days	
More than 100 000	1 day	1 sample per 10 000 population per month

[a] Applies to both disinfected and non-disinfected water systems. Source: *International standards for drinking-water* (*10*).

count. The criteria or standards adopted for local use must be clearly defined and circulated (in writing) to appropriate surveillance and waterworks personnel; above all, the criteria must be attainable by water supply systems of the sizes and types specified. Field studies in developing countries indicate that there is widespread use, in principle, of sampling standards adopted in the United Kingdom, USA, and other developed countries; in fact, except in a few capital cities these standards are not closely followed.

In accordance with the surveillance programme levels defined in Chapter 1, Table 7 outlines possible sampling schemes. It is again emphasized that these schemes are not final goals but are stepwise, interim stages in a formal plan of surveillance improvement leading ultimately to an ideal surveillance situation.

Table 7. Illustrative bacteriological sampling programmes for various levels of surveillance

Water supplied to:	Level of surveillance			
	I	II	III	IV
By the water producing agency[a]				
Rural areas and villages	none	none	none	none
Towns	none	none	monthly	monthly
Cities	see below and Table 6			
Other:				
institutions	voluntary	voluntary	voluntary	voluntary
temporary populations	varies with circumstances			
tankers	none	none	voluntary	voluntary
bottled water plants	none	voluntary	yearly	monthly
ice-making plants	none	none	voluntary	voluntary
By the surveillance agency				
Rural areas and villages	none	none	irregularly	irregularly
Towns	none	none	yearly	quarterly
Cities	monthly	monthly	monthly	monthly
Other (see Table 3):				
institutions	yearly	yearly	yearly	quarterly
temporary populations	none	varies	varies	varies
tankers	yearly	yearly	twice yearly	quarterly
bottled water plants	none	none	every 3 years	yearly
ice-making plants	none	none	every 3 years	yearly

[a] All chlorinated systems should be sampled and samples analysed for residual chlorine at least once a day. In larger systems sampling should be more frequent and samples for residual chlorine should be taken at various points in the distribution system.

The timing of sampling, other than routine programme sampling, generally follows that previously outlined for *ad hoc* sanitary surveys, that is, during epidemics, when new sources are being selected or water-mains disinfected, if accidental contamination occurs, and following consumers' complaints. Where bacteriological analysis indicates contamination, sampling accompanied by a sanitary survey, analysis of chlorine residuals, and remedial action, where applicable, should be continued until samples show no evidence of contamination.

Location of sampling points

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.

Many urban areas use water from several sources, often 3 or 4 and sometimes as many as 20 or more. Location of sampling points in the distribution system should ensure that water from each source is periodically sampled. Sampling should be more frequent for sources serving larger populations, surface water sources, sources serving older distribution systems, and sources with known water quality problems in the past.

Use of tank trucks (or "tankers") is a common method of distributing water in many large cities. In some cities, over half the population may receive their drinking-water by this means. Watering stations where the tank trucks are filled should be periodically sampled and the water distributed from the trucks should be randomly sampled without warning being given to the driver/purveyor. The trucks should be periodically cleaned and disinfected with chlorine at the watering station.

Collection of samples

Sample collectors must be instructed in the following sampling procedures.[a]

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[a] See Annex 8.

(1) 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.

(2) Location of sampling points, as described above. Subprofessional personnel should be specifically instructed about sampling sites.

(3) The use and purpose of dechlorinating compounds, such as sodium thiosulfate, added to the sampling bottle.

(4) Measurement of residual chlorine.[a] These tests must be performed immediately the sample is taken.

(5) 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" (*16*). Where samples are repeatedly contaminated by collectors, a complacent attitude may develop with regard to samples positive for coliform bacteria.

(6) 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.

Chemical sampling

Whereas frequent bacteriological examination is required for the hygienic control of drinking-water supplies, chemical examination is required much less frequently.[b]

Transportation of samples

Samples collected at some distance from the laboratory, especially those from outlying cities and towns, 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 should be a key factor in the location of regional laboratories.

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[a] See Annex 8.

[b] See *International standards for drinking-water* (*19*, p. 51).

Coordination with the laboratory

There is an obvious need for coordination between sample collectors and laboratory personnel; unfortunately, many examples exist of samples arriving at bus stations and remaining there several days before being collected, of samples reaching laboratories at week-ends, when they are closed, and of other faults of coordination that impair the usefulness of samples. A properly coordinated schedule must be established for the shipment of samples and their collection by laboratory personnel.

7. *Analysis of water samples*

Purpose

The primary purpose of surveillance is to ensure that drinking-water is safe. The bacteriological quality of the water is the main concern owing to the risk of epidemics of water-borne disease. Chemicals in the water may also be harmful and should not be forgotten. Laboratory tests for the bacteriological and chemical safety of drinking-water are outlined by Cox (*17*) and the American Public Health Association (*18*), in *International standards for drinking-water,* 3rd ed., 1971 (*10*) and more completely in the 2nd edition of this work published in 1963 (*19*), and elsewhere (*20–25*). These tests provide a valuable record of system performance, and properly selected sampling points can provide many indications of problem areas.

Chlorine residuals

As a method for continuous quality control of drinking-water bacteriological testing suffers from the drawback of requiring much time to produce results. The multiple-tube fermentation test for coliform bacteria requires 48–96 hours from sample collection to results, the membrane-filter test requires 18–22 hours. The most rapid test, on which research is still continuing, requires 8 hours. Furthermore, bacteriological testing requires certain laboratory skills and equipment that are often not available, especially outside major cities. The tests are also not inexpensive.

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 quickly performed, easily carried out, readily learned and inexpensive, and provides an immediate warning of abnormal or unsatisfactory water quality. The presence of a chlorine residual of ade-

Table 8. Minimum chlorine residual concentrations required for effective disinfection of water[a]

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

[a] After Butterfield (*26*) and Cox (*17*).

quate concentration for a sufficient length of time provides reasonable assurance that the water is free from pathogenic bacteria. Table 8 shows the residual chlorine concentrations necessary for effective disinfection, and two analytical tests for chlorine residuals are described in Annex 8.

Substitution of chlorine residual testing for bacteriological testing is permissible provided agreement is reached between the surveillance agency and the water supply management regarding the following points:

(1) 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;

(2) the minimum concentration and type of chlorine residual to be maintained;

(3) the analytical method to be used.

When chlorine residual testing is in use and 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. Should this sample also prove 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.

The drinking-water regulations of the USA are currently (1975) in the process of revision. When revised, the standards will allow the substitution of residual chlorine testing for bacteriological testing under prescribed circumstances (*50*). Even in countries with large resources, like the USA, the provision of bacteriological control for small water supplies is often difficult.

The membrane filter

The problems of bacteriological surveillance described above have led to considerable interest being shown in the developing countries in analytical tests using membrane filters. The membrane filters used in water bacteriology are flat, porous, flexible plastic discs about 0.15 mm in thickness and usually 47–50 mm in diameter. Pore size is rigidly controlled; for water bacteriology the pore diameter is typically 0.5 micrometre.

A water sample is filtered through the membrane filter, the filter is then placed on agar bacteriological culture medium or on a paper pad impregnated with moist culture medium, and the preparation is incubated for a specified time under prescribed conditions of temperature and humidity. The resulting bacterial culture is then examined and interpreted. This method of testing is approved and accepted by the World Health Organization and by many national surveillance agencies. The filters and filter-holders are available from manufacturers in a number of countries. In India the National Environmental Engineering Research Institute, Nagpur, manufactures filters.

Two principal advantages have been claimed for the use of membrane filters in developing countries.

(1) Rapidity; results are available in 24 hours in contrast to the 48–96 hours required for the standard fermentation-tube method.

(2) Portability; membrane-filter equipment for bacteriological examination of water is available in field kits from at least two manufacturers. One kit contains an all-metal syringe with a fitting for direct connexion to the culture container for producing a vacuum to draw water through the filter; bacteriological broth is supplied ready for use in glass ampoules and there is an associated equipment carrying kit and portable electrically heated incubator operating at 6, 12, 110, or 220 volts and accommodating 25 cultures. Components in this kit need not be sterilized in the field because filters, culture containers, and plastic filtration tubes are supplied in a sterile condition, and water samples do not come into contact with the syringe until they have passed through the filter. In another commercially available kit the funnel unit is sterilized through the incomplete combustion of methyl alcohol.

Other advantages are sometimes claimed, but these claims may or may not be justified.

(1) Cost: cost comparisons between membrane-filter and multiple-fermentation-tube methods of bacteriological examination include many debatable considerations. Surveillance agencies using both these methods in developing countries have given varied and conflicting responses to inquiries. Personnel at the United States Environmental Protection Agency's water supply research centre in Cincinnati, OH, consider that the costs are approximately equal for the two methods.

(2) Technical skill required: although sometimes said to be simpler, membrane-filter methods require laboratory skills and informed judgement of at least the same order as those required for multiple-tube tests. A skilled laboratory worker should receive a week's training and have an opportunity for further individual practice before he undertakes membrane-filter analyses.

The membrane-filter technique has certain limitations, especially with regard to its effectiveness in testing water that is highly turbid owing to the presence of algae or other materials, and it may not be possible to obtain significant results with samples of raw water. The presence of large numbers of non-coliform bacteria or of toxic substances may lead to low estimates of coliform bacteria. These limitations should be taken into consideration in applying the technique and interpreting results. Correct interpretation requires experience and a knowledge of the system under survey.

Detailed descriptions of the procedures are available in *Standard methods for the examination of water and wastewater* (*18*) and *International standards for drinking-water* (*10*).

There has been some objection to the high initial cost of commercially manufactured field testing units. Field units can be improvised by installing standard laboratory equipment in fibreboard carrying cases. A vacuum pump can be made by modifying a bicycle pump—reversing the leathers and fitting a bypass valve. Media are available as dehydrated preparations for reconstitution and sterilization in the field or as sterile liquid preparations in sealed ampoules; the latter have a shelf life of approximately 1 year when stored in the dark at moderate temperatures. Funnel units, graduated cylinders, media, etc., are sterilized by immersion in boiling water. In the absence of a portable incubator the filter can be placed in a Petri dish, which is then wrapped in polyethylene foil and placed close to the body for incubation.

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 waterworks 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 would also include analyses for toxic metals, pesticides, persistent organic chemicals, and radioactivity. In a well equipped laboratory with skilled personnel analysis of a single surface water sample could require 4 or more man-days in contrast to less than 1 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 selection of sources for large systems and occasional sampling.

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

Waterworks laboratories

Laboratory requirements and analytical methods are described in detail in *International standards for drinking-water* (*10*). Suggestions for laboratory testing in small outlying water systems are offered in this section.

The best laboratory instrument is an observant operator. Some analytical results—coliform bacteria counts, for example—are not available for several days. Yet, an operator who has observed a sudden change in raw water quality is not totally unprepared to act without waiting for results.

The hepatitis outbreak in Delhi has already been mentioned (p. 36). Although about 30 000 cases of hepatitis occurred there were no increases in typhoid or dysentery (*14*) because waterworks operators noticed a sudden dramatic increase in chloride concentration, an indicator of sewage pollution, and increased the alum and chlorine dosage. Unfortunately, though the residual chlorine concentration was bactericidal it was not sufficiently so in this instance to destroy hepatitis virus.

Every water production plant has its particular problems; moreover, every plant is faced with a different set of variables. It is essential, therefore, that a good operator should be able to recognize immediately when something is wrong with the water treatment plant, assess the dangerous or undesirable conditions that may exist, and, after taking appropriate action, determine how effective the action has been. To accomplish this the operator must be familiar with the results obtained in the water plant laboratory.

Facilities for laboratory tests needed to control the treatment processes should be provided at all filter plants. The minimum requirements at very small plants subject to technical supervision by an outside agency are facilities for making the following tests, where appropriate:

(1) turbidity measurements;
(2) colour determinations;
(3) flocculation characteristics (jar test);
(4) chlorine demand;
(5) residual chlorine levels.

Tests for pH, alkalinity, and ammonia should generally 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 fluorides is necessary when fluoridation is practised.

Equipment for physical and chemical testing of water is costly, and personnel using such equipment require technical training. Fortunately, however, the control tests listed above can be made to the accuracy needed for controlling the operation of smaller filtration plants by using special kits and chemical reagents, provided the directions are carefully followed. Colorimetric comparators particularly suitable for this purpose are produced by a number of manufacturers. Simplified methods for residual chlorine determinations and membrane-filter analysis are given in Annex 8.

Each filtration plant should have the following facilities so that the simple equipment provided may be properly used and stored:

(1) a small desk and chair;
(2) a work-bench 2 m long, 1 m wide, and 0.9 m high with a wooden top painted with black, acid-resistant paint and fitted with enclosed storage cabinets underneath;
(3) a bookcase or cabinet for chemicals;

(4) a sink with a water tap;
(5) 1 double-outlet water fixture to which rubber tubing may be connected;
(6) 1 ordinary water tap;
(7) 1 water tap with a screw fitting (male);
(8) 3 electrical outlets;
(9) 2 gas outlets when a gas supply is available.

These facilities may be located at the end of the operating gallery of small plants but should be in a separate room at larger plants.

Reference laboratory

Every surveillance agency should strive to have its own laboratory (or section of, say, a central laboratory maintained by the health ministry). In addition to analysis of drinking-water samples, activities might include the following:

(1) training of water treatment plant chemists;
(2) provision of reference standards;
(3) certification of water treatment plant laboratories;
(4) resale of culture media and other imported supplies to waterworks;
(5) evaluation of the safety of waterworks materials and chemicals, e.g., coagulant aids.

8. *Remedial action*

Correction of deficiencies

If sanitary deficiencies identified by the surveillance programme are not remedied the surveillance programme fails, and failure is perhaps worse than no surveillance because the existence of a programme may encourage false expectations of safety in the community water supply.

Failure of this final link in the chain of surveillance activities is, however, not uncommon. All too many central laboratories, for example, test bacteriological samples submitted and file their reports without notifying the waterworks from which the samples came of the results obtained, even when the samples show evidence of faecal contamination. Results must be reported back and a follow-up system implemented to ensure that remedial action is taken.

Waterworks should carry out their own chemical, bacteriological, and sanitary surveillance activities and, more importantly, should endeavour to institute remedial action before the intervention of the surveillance agency.

Urgency of action

Considerable judgement is required on the part of the evaluator in interpreting the relative effect of identified deficiencies on the safety and dependability of the water supply. When deficiencies are noted their seriousness must be evaluated, the cost of corrective action estimated, and judgement made on how available funds can best be used most effectively to obtain the maximum improvement per unit of cost.

An immediate decision is required on how urgent it is to correct the deficiency. The level of urgency is directly proportional to the health risk. For example, a chlorination failure during a cholera outbreak requires immediate correction, but installation of a standby chlorinator for a water system drawing its water from deep wells might take place at a normal pace without need for premium overtime payments and air transport of essential items.

Enforcement operation manual

Enforcement of remedial action may be assisted by the preparation and distribution to surveillance personnel of an agency guide or manual on enforcement operations. This manual might contain:

(1) background information on the surveillance programme;
(2) guides for staff conduct;
(3) inspection report forms together with instructions for completing the forms;
(4) copies of relevant laws and regulations;
(5) details of records procedures;
(6) an outline of notification procedure.
(7) suggested form-paragraphs for routine letters or typical violation notifications and recommendations for corrective action;
(8) follow-up form-letters.
(9) suggestions for establishing a reminder system for follow-up;
(10) guides on legal procedures in the event of non-compliance.

Legal action

The surveillance agency must have the power to require correction of serious deficiencies where waterworks have refused, or are unable, to make necessary corrections. Failure to enforce regulations, and especially written compliance orders, will inevitably weaken the regulatory agency's authority and compromise its effectiveness. Similarly, the water supply agency should enforce compliance with its own regulations and bylaws.

If legal action is initiated the surveyor must brief legal counsel and establish a file showing previous steps taken. An office conference or informal hearing with waterworks officials might precede court action.

Correction of deficiencies without legal compulsion

Despite the need for legal authority to force compliance if necessary, in most instances correction of deficiencies is achieved through persuasion, education, and motivation. Indeed, Salvato (*27*) suggests that

"... the primitive approach to sanitary regulation is police enforcement; the civilized approach is environmental health education; the sophisticated approach to law enforcement is self-inspection under regulatory surveillance and control."

Table 9 summarizes procedures used successfully in a Latin American city that lacks legal authority yet maintains a good surveillance programme. Although the scheme outlined in Table 9 works well in this particular city, it will not necessarily work elsewhere. It is important to note, however, that the surveillance agency has an organized, established procedure and has not used its lack of legal authority as an excuse not to act.

Table 9. Bacteriological sampling of water and reporting of presumptive (P) and confirmed (C) results for coliform bacteria in a Latin American city

Day Sample No.	0	1	2	3	4
1	Sample taken	P	C		
2		Sample taken	P	C	
3			Sample taken	P	C
4				Sample taken	P
Warning		1[a]	2[b]	3[c]	4[d]

[a] *1st warning.* If a sample is presumptive for coliform bacteria (gas formation): (1) the city water engineer is alerted by telephone, (2) the test result on the form is ringed with red ink, (3) the conclusion is typed in red on the form, and (4) a second sample is taken.

[b] *2nd warning.* If the first sample is confirmed positive and the second sample is presumptive: (1) a polite letter is written to the engineer, (2) the letter is delivered by hand, (3) a copy is sent to the director of the water supply, and (4) a third sample is collected.

[c] *3rd warning.* If the second sample is confirmed positive and the third is presumptive; (1) a letter is sent by hand to the director of the water supply with a clear notice that any subsequent letter will go to the mayor of the city, (2) a copy is sent to the engineer, and (3) a fourth sample is taken. [The third warning has been used twice in the recent history of the laboratory.]

[d] *4th warning.* If the third sample is confirmed positive and the fourth is presumptive, a letter is delivered by hand to the mayor of the city. [This step has not yet been taken.]

Another surveillance laboratory, in the event of a sample being found positive for coliform bacteria, notifies both the water utility (by telephone) and the appropriate regional engineers. Testing is repeated until the required standard is achieved.

Follow-up

Any survey that shows serious defects should be "tagged" for follow-up action. Such action depends on the nature of the defect. If the water supply appears to be contaminated *immediate action* is required. The most common immediate actions include increasing the chlorine dosage, flushing water mains, using an alternative source of water, advising consumers to boil drinking-water, eliminating cross-connexions, and stopping the service. Chlorine residual levels should be determined and bacteriological samples taken immediately. However, results of bacteriological examinations will often not be available for several days. When the sanitary survey shows that water, as distributed, is liable to faecal pollution, deficiencies should be corrected without regard to the results of laboratory examinations.

The surveillance authority must have the legal authority to support such actions. Some agencies, particularly those regulating small water systems and privately owned water supplies, have found it useful to have authority, should the water system management fail to respond, to carry out necessary work and recover the costs from the water system.

When immediate action is not required there should, nevertheless, be a follow-up. The most satisfactory method is generally to make another survey within, say, 30 days. For minor deficiencies, a letter from the water system manager reporting that the deficiency has been corrected may, if considered reliable, be adequate.

For multiple surveys, inspections, and other surveillance it is important to maintain a good record-keeping system. The "visible-file" system of colour coding files and "reminder" files is especially useful in follow-up procedures.

Failure to maintain active, forceful follow-up and supervision gives rise to apathy that soon spreads to the original surveys. Failure of supervisors to support inspectors when they meet with opposition is equally detrimental to the effectiveness of surveillance.

Limitations on remedial action

Evidence of water contamination by faecal pollution gathered during a survey, with or without laboratory confirmation, may be sufficient to condemn a water supply. The action of closing or forbidding use of a source carries an obligation to provide a safe alternative supply; otherwise, consumers may be driven to using an even more dangerous source of water. In some instances it may be better to initiate superchlorination, undertake immediate corrective measures, and warn water consumers to boil drinking-water. The objective of the sanitary survey is not so much to close down defective water supplies as to ensure that the consumer uses safe, potable water.

Assistance in emergencies

In emergencies the surveillance agency should support the waterworks management in its efforts to deal with the crises with material assistance such as supplies of chlorine, pumps, portable tanks, and other equipment. For further details refer to *Guide to sanitation in natural disasters* (*15*).

9. *Surveillance related to special systems*

Rural and village systems

In many developing countries three-quarters or more of the population live in rural areas and villages where water supplies present especially difficult surveillance problems because of the large numbers of systems in use and their geographical distribution, limited availability of funds, and lack of full-time, skilled waterworks operators. It is desirable for the surveillance programme to provide complete surveillance for these rural water supplies. However, this is likely to be impossible for some programmes owing to their limited financial and personnel resources. In the absence of formal surveillance programmes for rural areas the health or surveillance agency should nevertheless concern itself with the quality of rural community water supplies and should provide advice and health education for villagers.

Sanitary problems in rural systems are primarily attributable to unsatisfactory water sources, poor site selection, and constructional deficiencies. The priority of surveillance assistance to these supplies should be: technical assistance, training of local operators and sanitary aides, approval of sources, sanitary surveys, and bacteriological testing. Additional guidelines for small groundwater systems are given in Annex 4. Much useful information on rural water systems is to be found in three WHO publications: *Water supply for rural areas and small communities* (*28*), *Slow sand filtration* (*29*), and *Guide to simple sanitary measures for the control of enteric diseases* (*30*).

Slum and "fringe" areas

Slum areas within the cores of big cities and the rapidly growing "fringe" areas pose special surveillance problems. Although these problem areas may be served by a water distribution network, crowding of populations, lack of house connexions, intermittent service, low water pressures, leaks, and lack of sewerage may result in "high-risk" water distribution systems and insanitary surface water conditions. Slum and "fringe" areas are therefore susceptible to epidemics of water-borne diseases.

When piped water is not available the population may resort to local unsafe well water, contaminated surface waters, water tankers, or clandestine pilfering from a nearby system at unauthorized points that offer exceptional opportunities for contamination of the piped supply.

These problem areas should receive priority for extensions of the safe drinking-water supply. In the interim, surveillance should be particularly thorough.

Water systems serving transient populations

In surveillance, other things being equal, priority is given to larger populations at risk. Sanitary surveys of metropolitan water supplies should be implemented before regular surveillance is scheduled for village wells, etc.

As already stated, small water supplies serving transient populations may involve health hazards disproportionate to the size of the system. Rapid spread of epidemics of diseases such as cholera has been traced to contaminated water supplies at such sites. These supplies warrant high priority for surveillance, with particular emphasis on adequate chlorination. Preparations for a water supply for large gatherings should be made well in advance.

Bottled water supplies

Surveillance personnel in many countries, although displaying some interest in, and suspicion of, bottled water, take little action over surveillance of such supplies, which, however, present a potential threat to health and should be treated in the same way as other water supplies. Reasons for official apathy appear to be that expensive bottled waters consumed by tourists and wealthier citizens are "safe" and that the large numbers and small capitalization of other producers prohibit rigorous surveillance. Water supplied by itinerant vendors and hawkers should be viewed with particular suspicion. The best method of control is to eliminate the need for such vendors (and purveyors of bottled water) by the universal provision of safe, piped, public drinking-water supplies.

Regulations for bottled water manufacturing typically include requirements for quality; approval of sources; approval and periodic inspection of facilities records, and sanitation and maintenance practices; approval of bottles, caps and labels; and sampling and examination of water. The health agency should be empowered to ban the sale of bottled waters produced by suppliers unable to meet established standards.

Ice

Water for ice manufacture must be free from solids, bacteria, tastes or odours, and the dissolved mineral content must be as small as possible. Generally, most waters acceptable for domestic use are satisfactory for ice manufacture. Contrary to popular opinion, freezing does not kill bacteria, and all water used for ice-making should be of drinking-water quality since ice is frequently placed directly in drinks.[a]

The United States Public Health Service has published *A sanitary standard for manufactured ice* (*31*). This includes requirements for all water used in the ice-making process and for ice quality, cleaning of equipment, process sanitation, and transportation of ice, as well as for air and equipment, plumbing, housekeeping, toilet and hand-washing facilities, sewage and wastewater disposal, and health of personnel at the ice-making plant.

Food and beverage processing industries

The obvious possibilities for widespread transmission of disease by food and beverage processors indicate a special need for ensuring that these industries have safe water supplies. Water surveillance should be coordinated with the activities of the agency responsible for food sanitation, particularly in industries that provide their own water supply. More complete information is given in *Guide to simple sanitary measures for the control of enteric diseases* (*30*).

Emergency water supplies

Health hazards due to water supplies are often at their greatest during emergency situations such as earthquakes, hurricanes, floods, droughts, waterworks failures, and transport disasters. Contingency

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[a] When water freezes impurities present in the water tend to be "squeezed" towards the middle. Taking advantage of this phenomenon, ice manufacturers pass bubbles of air through the water during the freezing process, keeping it in motion and preventing precipitated chemicals, solids, and bacteria from freezing into the ice crystals. The impurities are thus concentrated in the core section (i.e., the unfrozen water in the middle of the block of ice). In the final stages of manufacture the core is removed ("pulled") and fresh water added in order to reduce the concentration of foreign matter before the final freezing. Inspection of a block of ice shows how well the core was pulled; discoloration in the middle of the block indicates contamination. Some minerals and chemicals that cause problems in ice manufacture are iron, manganese, calcium and magnesium carbonates, aluminium oxide, and silica.

planning for such events is essential for minimizing risks. Guidelines for emergency planning and operation have been recently published by WHO (*15*).

Institutional systems

Many water systems are not operated by, or for, municipalities or villages, yet they may serve large populations and should be kept under surveillance. These systems include those serving large housing projects, hospitals, schools, military encampments, prisons, airports, and hotels, and many of them purchase water in bulk from municipal water systems.

Annex 1

SPECIMEN SURVEILLANCE PROGRAMMES

SURVEILLANCE OF DRINKING-WATER QUALITY—LEVEL I

Description: This is an initial programme proposed for adoption in those countries that at present have no formal programme and a severely limited economic development.

Laws and regulations: Basic legal authority creating or designating the surveillance agency and empowering it to carry out the duties below.

Drinking water standards: Adoption of bacteriological standards in urban water systems.

Standard methods of analysis: As needed for above, plus residual chlorine testing.

Laboratory: Develop a central laboratory, possibly as part of the national health ministry laboratory.

Sanitary surveys: Programme for capital and major cities.

Approval of sources: Programme for capital and major cities.

Reporting requirements: Waterworks in major cities required to submit one sample of their finished water each month for analysis by the surveillance agency.

Design standards: Informal technical assistance.

Regulation of special water supplies: Government hospitals and major air, rail, and sea terminals.

Training: In-service training for surveillance staff; participation in international training programmes, if and when available; use of short-term consultants.

Technical assistance: On request, but no full-time staff on this task.

SURVEILLANCE OF DRINKING-WATER QUALITY—LEVEL II

Description: This is a basic programme for formal adoption in those countries that at present have nominal or superficial programmes with severe limitations on scope and effectiveness.

Laws and regulations: Basic legal authority authorizing the programme and powers sufficient to carry out programme below, including development of agency regulations.

Drinking-water standards: Adoption of bacteriological and physical standards in urban areas.

Standard methods of analysis: As needed for above, plus residual chlorine testing.

Laboratory: Establishment of a central water supply laboratory.

Sanitary surveys: Required for all city water supplies, emphasis on source and treatment.

Reporting requirements: All cities required to submit monthly samples. Major cities to report their own bacteriological tests. All supplies to monitor and report chlorine dosage and residual concentrations.

Approval of sources: All cities.

Design standards: Informal technical assistance.

Regulation of special supplies: Government hospitals, major transportation terminals, schools, army ports, prisons, large encampments, and tanker supplies in larger cities.

Training programme: Development of seminars for waterworks operators; some staff to be sent on international fellowships; use of consultant instructors; promotion of training efforts by local universities and technical institutions.

Technical assistance: As requested, limited programmes.

SURVEILLANCE OF DRINKING-WATER QUALITY—LEVEL III

Description: A programme intended for those countries that already have established programmes in major cities and are seeking to provide surveillance on a broader national or regional scale.

Laws and regulations: Basic legal authority plus well codified administrative regulations.

Drinking-water standards: Bacteriological, plus standards for turbidity, taste, colour, odour, and toxic substances.

Standard methods of analysis: Those appropriate to drinking-water standards.

Laboratory: Central water laboratory with capability for complete analyses; provision of key laboratory supplies to waterworks laboratories and training programmes for laboratory workers; regional laboratories if and when needed.

Sanitary surveys: Periodically in urban areas and a partial rural programme; routinely for new drinking-water sources in larger systems.
Approval of source: As above.
Reporting requirements: Regulations requiring plants to maintain records of operation. Samples to be submitted periodically to central laboratory.
Design standards: Publication of informal guidelines; consultation to be available.
Training: Development of short courses for surveillance and waterworks personnel; promotion of training efforts of local educational institutions, with financial support if necessary, and participation of professional staff in international training programmes including study tours and "internships" by senior staff.
Technical assistance: Advisory services on cross-connexions, plumbing, additives, material specifications, and rural water supplies.
Regulation of special water supplies: As for level II, plus all urban supplies, fairs, markets, housing projects, and larger bottlers and ice manufacturers.

SURVEILLANCE OF DRINKING-WATER QUALITY—LEVEL IV

Description: Programme intended for countries with well established surveillance programmes that seek to extend the service to the whole country and to increase the scope and effectiveness of surveys (particularly countries that are at "takeoff" point in their economic development).
Laws and regulations: Complete powers, but advisory rather than mandatory regulations for those activities lacking sufficient personnel for proper enforcement. Police power in any situation where a clear threat to health can be demonstrated.
Drinking-water standards: International standards for drinking-water or the equivalent, with appropriate adaptation to local conditions and publication in the national language.
Standard methods: International standard methods for drinking-water analysis published locally in the national language.
Laboratory: Establishment of a fully equipped central reference laboratory and regional facilities. Central laboratory to provide many services including training, technical assistance, bacteriological media, standards, and evaluation of other laboratories.
Sanitary surveys: All urban areas including distribution systems; most larger rural community supplies to be surveyed at regular intervals.
Approval of sources: All new sources for community water systems require preconstructional agreement between the waterworks management and the surveillance agency.

Reporting requirements: Regulations requiring larger plants to maintain records of operation and laboratory analyses; samples to be submitted to, or taken by, the surveillance agency on an established schedule.

Design standards: Formal programme for preconstructional agreement of new works for largest systems; published guidelines.

Plumbing code: Codified and enforced in major cities and for major manufacturers of plumbing fixtures.

Training: Strongly supported programmes of short courses; support for institutional training and educational programmes; and operation of a technical institute if necessary.

Technical assistance: Active programme with full-time staff.

Regulation of special supplies: All supplies serving significant population numbers and bottled water production and ice manufacture.

Other: Cross-connexion control programme; formal participation in health education programme of the health ministry.

Annex 2

MEDICAL EXAMINATION OF WATERWORKS OPERATORS

The following extract is taken from *Safeguards to be adopted in the operation and management of waterworks* published by the United Kingdom Ministry of Housing and Local Government, Welsh Office (*32*).

"(i) Care should be exercised in the selection of men to be employed on works where a risk to the purity of the water supply is likely to arise. The clinical history of each man, particularly with reference to any infection capable of being water-borne, should be throughly investigated and he should be examined by testing his blood to determine whether or not he is likely to be a typhoid carrier. When blood tests give a positive result which is not attributable to preventive inoculation, he should not be so employed unless repeated examination of his stools and urine fails to show the presence of pathogenic bacteria."

"(ii) If preliminary blood tests are not used, bacteriological examination of stools and urine must be carried out on at least three occasions at weekly intervals in all cases. This should reveal 70–80 per cent of chronic carriers."

"(iii) If any employee is known to have any disease that could be water-borne or is suffering from an illness associated with looseness of the bowels or an illness necessitating his absence from work for more than five days there should be standing arrangements to ensure that he is not employed on work where a risk to the purity of the water supply is likely to arise until he has been seen by the undertaking's medical officer who will decide whether examination on the lines indicated above is necessary to show that it is safe for him to be so employed. Standing arrangements should also be in force to ensure that each member of the staff is examined by the undertaking's medical officer at intervals of not more than three years."

Annex 3

TRAINING COURSES[a]

COURSE: SANITARY SURVEYS

Trainees: Municipal waterworks supervisors and senior operators;
public health sanitarians and sanitary technicians;
junior sanitary engineers

Duration of course: 3 consecutive days; alternatively, 6 evening sessions each lasting 3 hours, plus a 1-day field trip during daylight hours

Class size: 10–20 persons

Physical facilities:

Classroom in plant, school, or office building equipped with blackboard and sufficient student desks

Laboratory for water testing (chemical and bacteriological) in water treatment plant or government institution

Field trips to municipal waterworks source, treatment and distribution plant, rural water supplies using wells

Equipment and supplies:

For demonstrations: prepared flip-charts (one set), mimeographed documents and survey forms (one set per student)

For practical classes: residual chlorine comparators (1 per 4 students), sterile sample collection bottles (2 per student)

Transportation needs: A bus or cars or trucks for field trips every day

Course curricula for sanitary surveys

Day	Time	Duration	Location	Curriculum details	References[a]
1	08.00–09.00	1 hour	Class-room	Sanitary surveys: definition timing and frequency rural water supplies town water supplies major city waterworks	**A**, pp. 23–25, 36–44
	09.00–10.00	1 hour	Class-room	Personnel: qualifications water plant operators training operators occupational health and safety public relations	**A**, pp. 30–35 **B**, pp. 246–250

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[a] Adapted, in part, from Rajagopalan & Shiffman (*30*).

Course curricula for sanitary surveys *(continued)*

Day	Time	Duration	Location	Curriculum details	References[a]
	10.00–11.00	1 hour	Class-room	Programme administration: organization records follow-up measures	A, pp. 20–26, 59–62 B, pp. 244–245
	13.00–17.00	4 hours	Field	Field trip to typical rural water system	A, Annex 4, pp. 82–99
2	08.00–10.00	2 hours	Class-room	Water sources (*a*) Groundwaters: aquifer characteristics pollutional influences development protection of wells, springs, etc. (*b*) Surface waters: watershed considerations analyses intake structures	A, Annex 4, pp. 82–99 C, pp. 57–120 B, pp. 11–13 C, pp. 161–170 E, pp. 6–9 E, pp. 6–9
	10.00–12.00	2 hours	Class-room	Water treatment: conditioning filtration (i) rapid sand filters (ii) slow sand filters disinfection equipment records	A, pp. 84–86 C, pp. 171–193 B, pp. 94–133
	13.00–17.00	4 hours	Field	Field visit to municipal water plant	A, Annex 4, pp. 82–99
3	08.00–10.00	2 hours	Class-room	Distribution systems: design of networks siting and construction of storage reservoirs disinfection of new work taking samples losses in system records	A, Annex 4, pp. 87–90 C, pp. 194–223 D, p. 9
	10.00–11.00	1 hour	Class-room	Water distribution problems (*a*) Water leaks: effect on quality methods of treating leaks (*b*) Cross-connexions: physical correction backflow prevention finding cross-connexions control programme	A, Annex 5, pp. 100–107 E, pp. 47–52

Course curricula for sanitary surveys *(continued)*

Day	Time	Duration	Location	Curriculum details	References[a]
3	11.00–12.00	1 hour	Classroom	Evaluation	
	13.00–17.00	4 hours	Field	Visit to different elements of a municipal water distribution system	A, Annex 4, pp. 82–99

[a] The references refer to the following publications:
A — this monograph;
B — Cox (*17*);
C — Wagner & Lanoix (*28*);
D — United States Environmental Protection Agency (*33*);
E — United Kingdom, Welsh Office, Ministry of Housing and Local Government (*32*).

COURSE: BACTERIOLOGICAL SAMPLING AND TESTING BY MEANS OF MEMBRANE FILTERS

Trainees: Operators from larger municipal waterworks;
waterworks chemists and bacteriologists;
laboratory chemists and bacteriologists;
laboratory assistants

All having had previous training and experience in bacteriological analysis of waters

Duration of course: 5 days (students will carry out membrane-filter tests)

Class size: Maximum of 8 students per instructor

Physical facilities:

Classroom in office building, school, or plant equipped with desk space

Laboratory for water testing (chemical and bacteriological) in water treatment plant, school, or government institution

Field trips to municipal waterworks source, treatment, and distribution plant for sample collection; also visits to dug wells if readily accessible

Workshop for laboratory tests

Equipment and supplies:

For demonstrations: residual chlorine comparators (1 per 4 students) stills, sterilizers, media, bottles, membrane filters, incubators, etc., for bacteriological analysis

For practical classes: same equipment needed

Transportation needs: A bus or cars or trucks for field trips on days 2, 3, and 4

Course curricula for bacteriological sampling and testing by means of membrane filters

Day	Time	Duration	Location	Curriculum details	References[a]
1	08.00–10.00	2 hours	Classroom	Water-borne diseases Indicator organisms Coliform group of organisms Standards for water safety Disinfection	B, pp. 174–181
	10.00–12.00	2 hours	Classroom	The membrane filter: advantages and disadvantages filter characteristics Media Field equipment Laboratory equipment Incubation	B, pp. 347–352 A, pp. 53–54; Annex 8, pp. 122–125
	13.00–17.00	4 hours	Laboratory	Familiarization in use of membrane filter and field monitoring equipment following demonstration of techniques Collection and analysis of sample from the building system	E
2	08.00–09.00	1 hour	Classroom	Sampling theory Frequency of sampling Size of samples Number of samples Economic limitations	A, pp. 44–48 B, p. 279
	09.00–10.00	1 hour	Classroom	Selection of sampling points; representative samples Point of entry to distribution system Principal portions of system Avoidance of dead-ends Limitation of raw water testing	A, p. 48 C, pp. 271–275
	10.00–11.00	1 hour	Classroom	Field sampling procedures: transportation considerations prompt versus delayed examinations shipment of samples	D
	11.00–12.00	1 hour	Classroom	Laboratory bacteriology: sterilization nutrient media incubation	
	13.00–17.00	4 hours	Laboratory and field	Field collection of samples from distribution system point followed by laboratory examinations using membrane filter	A, Annex 8, pp. 122–125 E
3	08.00–09.00	1 hour	Classroom	Recording results of tests: statistical validity monthly summarizations systems evaluations	

Course curricula for bacteriological sampling and testing by means of membrane filters *(continued)*

Day	Time	Duration	Location	Curriculum details	References[a]
3	09.00–10.00	1 hour	Classroom	Positive samples: disinfection requirements repeat testing	
	10.00–11.00	1 hour	Classroom	Monitoring programme: equipment and supplies needed transportation considerations	**C**, pp. 46–50
	11.00–12.00	1 hour	Classroom	Securing corrective action: liaison between agencies administrative channels water authority health authority	**A**, pp. 58–61
	13.00–17.00	4 hours	Laboratory and field	Field collection of samples from distribution system points followed by laboratory work recording results of previous day's examinations	**E**
4	08.00–17.00	1 day	Field and laboratory	Continuation of supervised collection of field samples and laboratory examinations by the membrane-filter technique until proficiency is demonstrated (i.e., about 10 samples and examinations per student for those without previous experience)	
5	08.00–12.00	4 hours	Classroom	Summarizing of findings: interpretation preparation of report forms question and answer period course evaluation	

[a] The references refer to the following publications:
A — this monograph;
B — Cox (*17*);
C — Wagner & Lanoix (*28*);
D — Panezai et al. (*34*);
E — manufacturers' literature dealing with the particular equipment employed.
The reader is also referred to the various publications mentioned in Chapter 7.

COURSE: CONTROL OF CROSS-CONNEXIONS

Trainees: Municipal waterworks distribution foremen;
sanitarians and public health inspectors;
plumbers
Duration of course: 2 days
Class size: 6-12 persons
Physical facilities:

Classroom in office building, school, or plant (if equipped with desks)

Field trips to water distribution system, industrial sites, wells, pumping station, etc.

Equipment and supplies:

For demonstrations: sounding rods, dyes, pressure gauges, flip charts, vacuum breakers, check valves, vacuum tank or pump for demonstration of back-siphonage

For practical classes: residual chlorine comparators (1 per 4 students)

Transportation needs: 1 bus

Course curricula for control of cross-connexions

Day	Time	Duration	Location	Curriculum details	References[a]
1	08.00–09.00	1 hour	Classroom	Definitions Historical review and examples Hydraulic principles, negative pressures	A, Annex 5, pp. 100–101 D, pp. 3–8; E, pp. 7–10 D, pp. 9–18
	09.00–10.00	1 hour	Classroom	Sanitary surveys, dual systems: methods of elimination separation of supplies air gap installations; how measured	A, Annex 5, pp. 102–104 D, p. 46 D, pp. 19, 51 E, p. 48
	10.00–12.00	2 hours	Classroom demonstrations	Backflow and siphonage prevention: non-pressure vacuum breakers pressure vacuum breakers reduced pressure principle backflow preventer check valves	E, p. 13 D, p. 27 D, p. 17, Fig. 18 D, p. 30 D, pp. 29, 30
	13.00–17.00	4 hours	Field	Field trip to distribution portions of municipal waterworks, pumping stations, storage, etc.	

Course curricula for control of cross-connexions *(continued)*

Day	Time	Duration	Location	Curriculum details	References[a]
2	08.00–09.00	1 hour	Classroom	Plumbing codes, ordinances, legislation	**A**, pp. 27–29 **B**, p. 251 **D**, pp. 35–42 **E**, pp. 37–38 **D**, pp. 32–34
	09.00–11.00	2 hours	Classroom	Control programme organization: manpower considerations educational campaigns cooperation with industry design reviews plant inspections	**C**, pp. 245–246 **C**, p. 23
	11.00–12.00	1 hour	Classroom	Enforcement measures	**A**, pp. 59–60
	13.00–17.00	4 hours	Field	Field trip to visit representative commercial and industrial operations with and without auxilliary water sources	

[a] The references refer to the following publications:
A — this monograph;
B — Cox (*17*);
C — Wagner & Lanoix (*28*);
D — United States Environmental Protection Agency (*35*);
E — United Kingdom Department of the Environment (*36*).

COURSE: OPERATION OF WATER TREATMENT PLANTS

Trainees: Waterworks supervisors, operators, and chemists;
sanitarians;
engineers

Duration of course: 5 days

Class size: 10–20 persons

Physical facilities:

Classroom in office building, school, or plant (to be preferred if desks and space can be arranged)

Laboratory for water testing (chemical and bacteriological) in plant, school, or governmental institution

Workshop (laboratory control of operation) in plant equipped with suitable laboratory

Field trips to pumping station, source, and well supply

Equipment and supplies:

For demonstrations: jar tests, apparatus for measuring pH, alkalinity, turbidity, chlorine demand, residual chlorine, taste, colour, odour, etc.

For practical classes: residual chlorine comparators (1 per 4 students)

Transportation needs: 1 bus

Course curricula for operation of water treatment plants

Day	Time	Duration	Location	Curriculum details	References[a]
1	08.00–09.00	1 hour	Classroom	Source protection measures: pollution control watershed considerations protection of wells and springs	**A**, pp. 63–64; Annex 4, pp. 82–84 **B**, pp. 1–13
	09.00–10.00	1 hour	Classroom	Reservoir considerations: storage effects stratification and overturn intake locations algal growths	**B**, pp. 14–20
	10.00–11.00	1 hour	Classroom	Taste and odour problems: causes treatment (i) copper sulfate (ii) aeration (iii) chlorination (iv) adsorption	**B**, pp. 29–53
	11.00–12.00	1 hour	Classroom	Coagulation and flocculation: coagulant chemicals jar testing dosing and mixing floc formation; flocculation aids	**B**, pp. 54–78
	13.00–15.00	2 hours	Classroom	Sedimentation: basin designs, detention time inflow distribution settling times effluent weirs sludge removal short-circuiting	**B**, pp. 79–93
	15.00–17.00	2 hours	Classroom	Slow sand filters: design considerations flow controls rates of operation cleaning	**D** **B**, pp. 94–99; 178 **C**, pp. 175–178
				Rapid sand filters: design considerations rates of operation backwash methods rate controls	**B**, pp. 99–127
				Pressure filters	**B**, pp. 127–128

Course curricula for operation of water treatment plants *(continued)*

Day	Time	Duration	Location	Curriculum details	References[a]
2	08.00–12.00	4 hours	Classroom	Disinfection: chlorine measurement prechlorination postchlorination breakpoint chlorination super-chlorination Disinfection chemicals: hypochlorinators chlorinators	**B**, pp. 134–171; **C**, pp. 185–193; **E**, p. 31
	13.00–17.00	4 hours	Field	Field visit to water sources utilized in the area for water production and accomplishment of supervised sanitary surveys of the various sources	**A**, Annex 1, pp. 67-70; Annex 4, pp. 82-99; Annex 6, pp. 108-115
3	08.00–09.00	1 hour	Classroom	Public health principles of water quality: physical chemical bacteriological biological	**B**, pp. 172–182; **E**
	09.00–10.00	1 hour	Classroom	Laboratory and testing procedures	
	10.00–12.00	2 hours	Classroom	Sampling requirements: representative samples sampling time composite samples sampling equipment	
	13.00–17.00	4 hours	Field	Visit to surface water treatment plant; supervised sanitary survey of various treatment units	**A**, Annex 4, pp. 84-90; Annex 6, pp. 108-115
4	08.00–09.00	1 hour	Classroom	Water plant records: daily measurements and tests periodic measurements and tests permanent record requirements	
	09.00–10.00	1 hour	Classroom	Computation of solutions and doses; plant arithmetic	**B**, pp. 254–256
	10.00–11.00	1 hour	Classroom	Storage of chemicals and supplies: precautions with chemicals protective equipment emergency measures	

Course curricula for operation of water treatment plants *(continued)*

Day	Time	Duration	Location	Curriculum details	References[a]
4	11.00–12.00	1 hour	Classroom	Pumping stations and distribution system pressure requirements	
	13.00–17.00	4 hours	Field	Visit to groundwater developments in local area — wells, springs, galleries, etc.; supervised sanitary survey of system elements	**A**, Annex 4, pp. 82-83; Annex 6, pp. 108-115
5	08.00–12.00 13.00–15.00	6 hours	Laboratory	Demonstration and practice: chlorine residual testing turbidity determinations pH testing jar test for coagulant dosages. other tests	
	15.00–17.00	2 hours	Classroom	Review of course material; questions and answers; evaluation of course	

[a] The references refer to the following publications:
A — this monograph;
B — Cox (*17*);
C — Wagner & Lanoix (*28*);
D — Huisman & Wood (*29*);
E — United States Environmental Protection Agency (*33*).

Annex 4

SANITARY SURVEY GUIDELINES

The following outline lists essential factors that should be investigated or considered in a sanitary survey.

Sources

As indicated, each new source should be inspected prior to its adoption as a source of drinking-water. A source that is satisfactory today cannot be expected to be always free from risk in the future; periodic resurveys are necessary.

Groundwater

Generally speaking, when good quality groundwater is available in sufficient quantity it is to be preferred. More frequently than water from other sources, groundwater can be expected to be clear, colourless, and of better bacterial quality. Of course, clarity does not automatically guarantee bacterial purity and, indeed, many wells, especially open "dug" wells, "have always presented a sorry tale" (*37*). Because many well waters are unchlorinated, a measure often recommended but seldom practised, their sanitary protection is particularly important. Three factors are particularly important in evaluating the sanitary quality of well water: geology (safety of the aquifer), distance from sources of pollution, and sealing of the well from surface contamination.

Geologically related hazards frequently arise when aquifers are shallow with watertables close to the surface or when "shortcut" routes exist (faults or channels in soluble rock such as limestone) through which polluted waters reach wells.

A safe distance between a well and a source of pollution is difficult to define except as "a distance that ensures that no contamination will reach the well". The distance should be the maximum that economics, land ownership, geology, and topography permit: as a guideline, a minimum of 10 metres is frequently suggested. The well should be situated on a surface elevation above surrounding sources of contamination and should be protected from flood waters.

The third common hazard, that of contamination by surface waters, can be largely avoided by proper construction of wells as outlined, for example, by Wagner & Lanoix (*28*) and Rajagopalan & Shiffman (*30*). These practices include construction of well seals and covers, extension of well casings to at least 15 cm above the well-house floor and into the impermeable stratum immediately above the aquifer, the provision of proper venting, watertight pump connexions, and locks on wells and pump houses, and the disinfection of new construction work.

Surface water

For surface water, a sanitary survey and laboratory analysis of raw water samples indicate the suitability of the source and the degree of treatment desirable. Analyses should preferably include counts of coliform bacteria and determinations of water turbidity, colour, odour, and objectionable and toxic constituents as listed in *International standards for drinking-water* (*10*).

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 distribution system 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. In one particular epidemic, floating bodies of cholera victims were observed actually passing across the open mouth of the intake downstream. Conversely, an intake set too low may draw in mud and sediment from the bottom; this, even if not actually infective, may interfere with the proper working of pumps and filters. If the draw-off cannot be located clear of the main stream, it may be feasible to divert the current by means of a spur wall constructed from sandbags. Another hazard that should be noted is the possibility of counterflow. In an outbreak of infectious hepatitis in 1955 (*38*) 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.[a] Such devices may not only improve the quality of the raw water but also, by reducing the load on the treatment plant and stabilizing the quality of the water to be treated, increase the capacity of the plant quantitatively.

Treatment

Most surface water will require filtration, but filtration is often preceded by storage, coagulation, and sedimentation or other processes that, while effecting some purification, have the advantage of conditioning the water to improve the efficiency of the filtration stage. Filtration must be followed by disinfection, chlorine being the most frequently used disinfecting agent. In a well designed and well operated works disinfection supplies the final defence against water-borne bacteria. The aim should be to produce clean, clear water from the filter and then to add sufficient chlorine to ensure bacteriological purity and provide a protective residual within the distribution system. These efforts are summarized in Fig. 1.

Combined chlorine kills bacteria much more slowly than does free chlorine so it is desirable to treat water to maintain a residual of free chlorine for a contact period of at least 1 hour in order to kill bacteria and viruses. If the raw untreated water has a high organic content prechlorination may be necessary. Postchlorination may also be necessary to ensure an adequate free residual chlorine concentration.

While many small plants will not be capable of carrying out bacteriological analyses, all should be able to test for residual chlorine. When small systems are chlorinated this test will be the single most important method of surveillance at the treatment plant.

Thus, the survey officer should report on the following questions. Is chlorination practised, is the equipment adequate and is it safe, is standby equipment available in the event of a breakdown, are chlorine reserves maintained at adequate levels, and is chlorination effective? Does the plant maintain adequate records and chlorine testing apparatus? Are the operators qualified?

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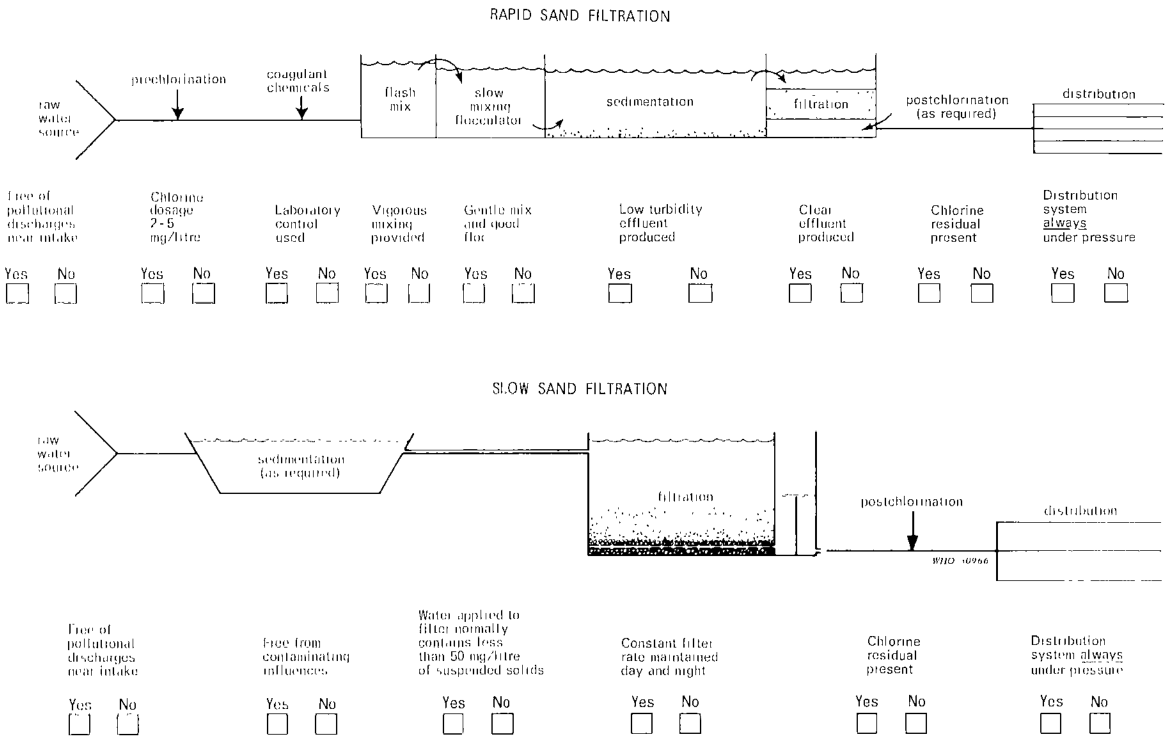
[a] Sediment removal facilities may be necessary for highly turbid raw waters; control of algae may be required in some instances.

Fig. 1. Checklist for surface water treatment plants[a]



RAPID SAND FILTRATION

SLOW SAND FILTRATION

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[a] After Rajagopalan & Shiffman (*30*).

The operation and control of rapid sand filters is described in detail in *Operation and control of water treatment processes* (*17*). The operation of filters should be controlled by tests for turbidity and colour and by bacteriological examinations of the water. The objective should be to produce water with a turbidity of less than 0.5 Jackson unit (JTU). In well operated plants turbidity will not normally exceed 1.0 JTU; turbidities greater than 5 JTU are detectable by consumers.

Slow sand filters are simple to operate, requiring relatively unskilled labour, 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 & Wood (*29*).

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 book-keeping 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:

(*a*) the date of last cleaning;

(*b*) the date and hour of return to full service (i.e., end of the ripening period);

(*c*) raw and filtered water levels (measured each day at the same hour) and the daily loss of head;

(*d*) the filtration rate and the hourly variations, if any occur;

(*e*) the quality of the raw water, including temperature, turbidity, colour, 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);

(*f*) the same quality parameters for the filtered water; and

(*g*) 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.

The sanitary surveyor should inspect the various unit processes and operations to ensure that they are operating satisfactorily: for example, that the mechanical equipment such as rapid mixers and flocculators are working, that all chemical feeding and dosing equipment is in order and well maintained, that adequate chemical supplies are on hand, and that the floc particles are not being broken up before settling or being carried over from the top of the "blanket" or column of settled floc into the weirs and on to the filters. The prefiltration processes are also important to the protection of health by directly removing pathogenic agents such as bacteria, cercariae, cysts, and spores; enhancing the effectiveness of filtration and chlorination; and providing partial "defence-in-depth" in the event of a failure in another process. The surveyor should observe particularly whether any treatment processes are being bypassed.

Distribution

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:

(*a*) insufficient treatment of water at the production plant;

(*b*) cross-connexions;

(*c*) improperly protected distribution system storage;

(*d*) inadequate disinfection of water mains and failure to maintain chlorine residuals in the system;

(*e*) unsatisfactory construction and repair of water mains;

(*f*) close proximity of sewers and water mains;

(*g*) improperly constructed, maintained, or located blow-off, vacuum, and air relief valves;

(*h*) negative or low pressures and intermittent or interrupted flows in the distribution system;

(*i*) improper consumer plumbing practices (direct connexion of booster pumps, for example);

(*j*) leakages, especially when combined with low pressures;

(*k*) dead-end mains;

(*l*) faulty hydrants; and

(*m*) faulty maintenance.

The distribution system of a water supply offers many opportunities for impairment of water quality. The retention time of water within the mains of the system may be quite long and there are usually many potential inlets for polluting materials—leaks, service taps, blow-off and relief valves, and cross-connexions, etc. A complete list of protective measures must include proper procedures for the laying, flushing, and disinfecting of new or repaired water mains; maintenance of chlorine residuals when a main is returned to service; and adequate separation of water and sewer lines. Water quality can be adversely affected by improperly constructed or installed blow-off and relief valves or by valves located in sumps that are subject to flooding or in other places liable to inundation by wastes or poor quality water. Dead-end mains should be avoided.

The system should be designed to supply adequate quantities of water under ample pressure and should be operated to prevent conditions leading to the occurrence of negative pressure. Steps to prevent negative pressure should include minimizing planned shutdowns, providing adequate supply capacity, replacing undersized piping, and selecting and locating booster pumps correctly to prevent the occurrence of a negative head in piping subject to suction. Continuity of service and maintenance of an adequate pressure throughout a public water supply system are essential for preventing back-siphonage.

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 10%, and certainly if they exceed 30%, 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 connexions.

Locating leaks: A skilled inspector using a sounding rod can accurately locate a leak in 80% of cases (*39*). Evidence that may directly or indirectly lead to the location of a leak includes:

(*a*) knowledge of other services crossing the line of the main;
(*b*) existence of recent excavations for other services;
(*c*) discoloration of walls or buildings;
(*d*) growth of moss on walls;
(*e*) uneven and discoloured road surfaces;
(*f*) uneven pavements;
(*g*) recent severing of water supply to old services;
(*h*) reports on hydrants recently used by contractors, fire brigades, and other persons;
(*i*) loss of supply or reduction of pressure in adjacent premises;
(*j*) noise in services, water mains, and household plumbing;
(*k*) presence of surface water;
(*l*) growth of vegetation;
(*m*) melting of snow or frost;
(*n*) abnormal reduction of residual chlorine; and
(*o*) consumers' complaints about dirty water.

The available time is best spent in searching first for the biggest and most troublesome leaks. A detailed leak location investigation should be made first on those portions of the system found to have a higher than average rate of leakage.

When the area, or line, in which there is a leak is known use a pipe locator 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 *(39)*.[a]

Storage of finished water

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 m of a storage reservoir with a floor below ground level should be strongly constructed with sound, tested, watertight joints. No sewer should be located closer than 3 m to a reservoir.

The ground surface above the reservoir should be graded to drain surface water away from the reservoir and prevent pooling of surface water within the vicinity. Walls or fencing should surround all service reservoirs and public access should be prohibited.

Any overflow, blow-off, or clean-out pipe from a storage reservoir should discharge freely into an open basin from a point located not less than 3 discharge pipe diameters above the top or spill line of the open basin. All overflow, blow-off, clean-out, or vent pipes should be turned downwards to keep out rain and should be screened with removable fine-mesh screens to exclude birds, bats, rodents, insects, and contaminating materials. All inlet and outlet pipes of storage reservoirs should be properly supported and constructed to minimize the effects of settling, and wall castings should be provided with suitable collars to ensure watertight connexions.

A suitable and substantial cover should be provided for any reservoir,

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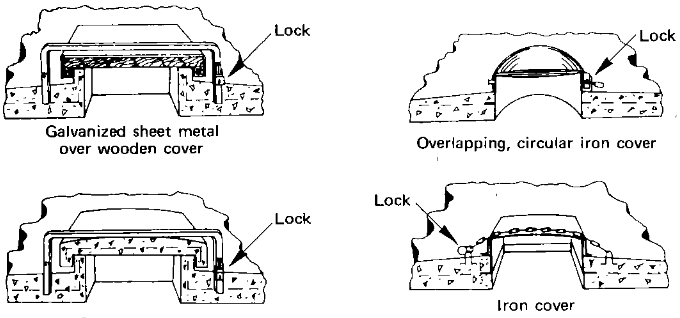
[a] Subsequently renamed National Environmental Engineering Research Institute.

Fig. 2. Possible arrangements for vents and manhole covers for water supply constructions[a]



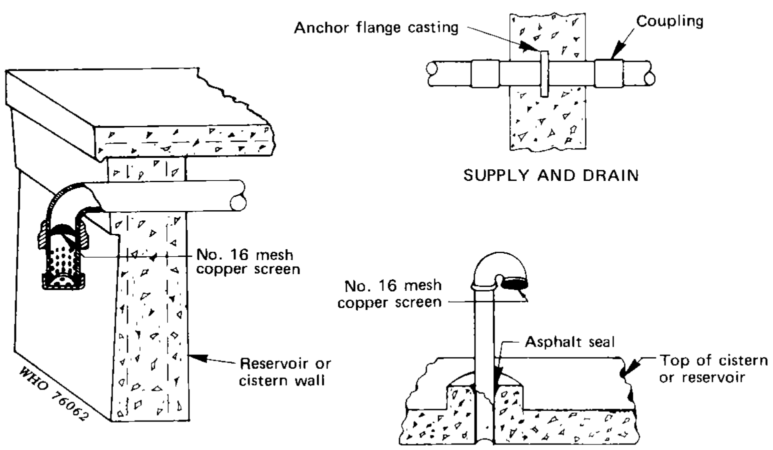
Galvanized sheet metal over wooden cover

Overlapping, circular iron cover

Concrete cover

Iron cover

MANHOLE COVERS



SUPPLY AND DRAIN

OVERFLOW AND VENT

ROOF VENT

[a] Adapted from *Manual of individual water supply systems* (41).

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. Fig. 2 shows possible arrangements for vents and manhole covers in reservoirs.

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.

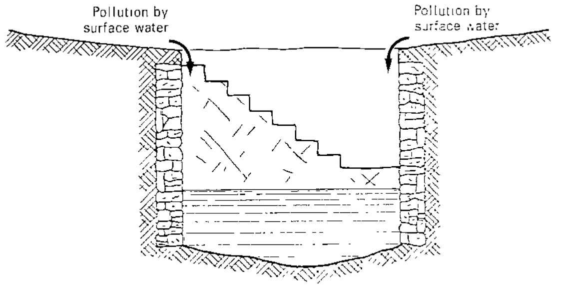
Rural and village supplies

On account of their large numbers, most rural and village water supplies are generally surveyed, if surveyed at all, by sanitary aides. Water quality problems in these systems are most often traceable to (1) poor site or source selection or (2) construction deficiencies. Fig. 3–11 provide guidelines for surveillance of rural and village supplies by sanitary aides (*30*).

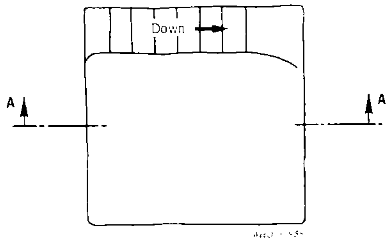
Common sanitary defects

Some of the more frequent, readily identified, and preventable sanitary deficiencies in water supplies are listed below. Each deficiency has been shown to have resulted in contaminated water and is therefore an obvious target for scrutiny in suspect water supplies. The lists could be expanded considerably; they are neither complete nor universally applicable. The examples given illustrate two points. First, in any new works possibilities for contamination should be anticipated and avoided at the design stage by proper source selection and design practices; sec-

Fig. 3. Insanitary step-well[a]



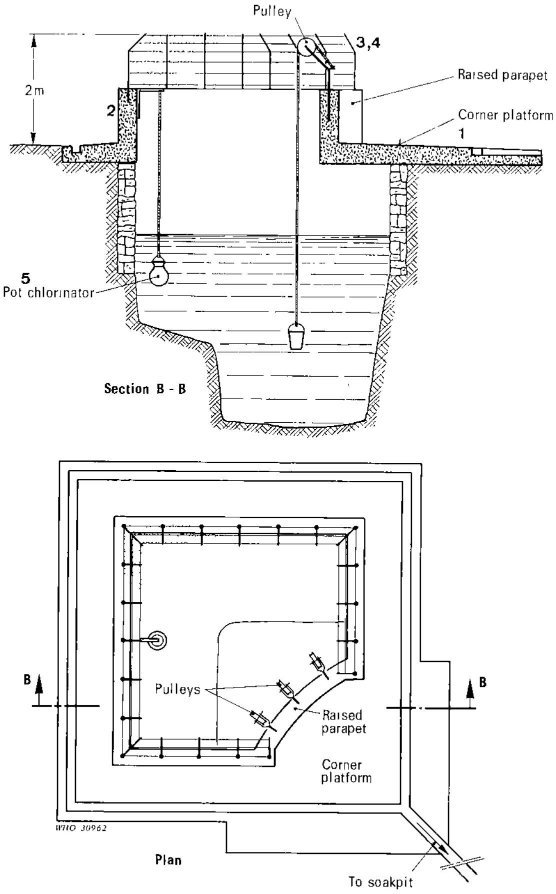
Section A - A



Plan

[a] After Rajagopalan & Shiffman (unpublished).

Fig. 4. Improved step-well[a]



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?

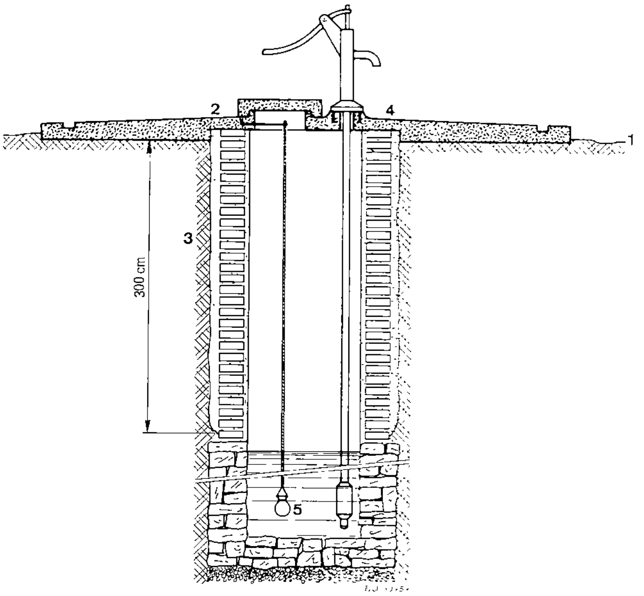
[a] After Rajagopalan & Shiffman (*30*).

ond, periodic surveys should be made of existing physical works and operational practices to identify and correct existing or potential health hazards. See also references *17, 27, 32, 33,* and *40.*

Groundwater sources

(1) 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;

Fig. 5. Dug well with pump[a]



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?

[a] After Rajagopalan & Shiffman (*30*).

(2) 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;

(3) 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;

(4) supply sources or adjacent structures that are subject to flooding;

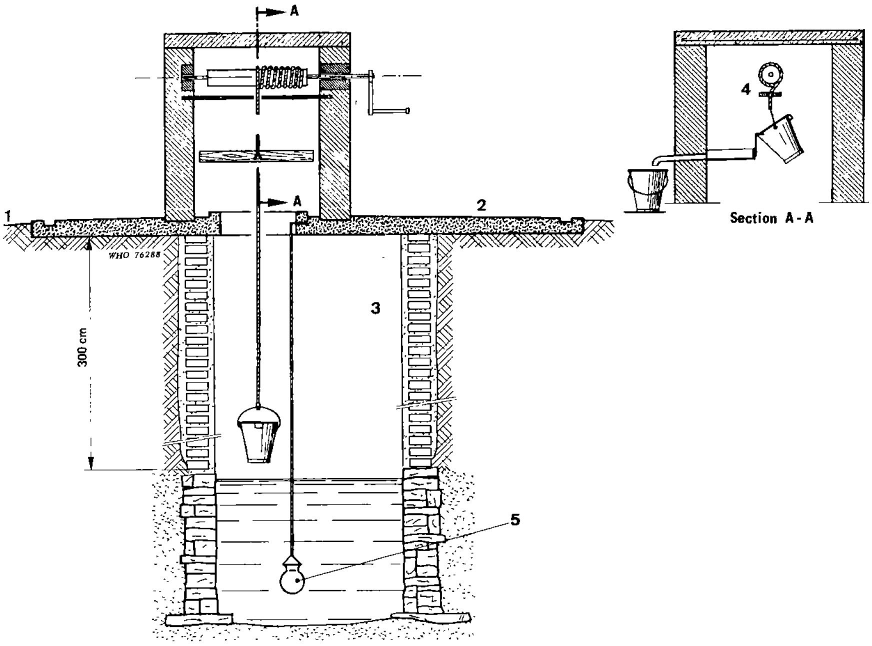
(5) use of tile pipes or other conduits that are not watertight in locations where the groundwater may be contaminated;

(6) leaks in systems under vacuum;

(7) air-lift line or lines cross-connected to a sewer or secondary water supply;

(8) wells located near sewers, pit privies, cesspools, septic tanks, subsurface tile systems, drains, barnyards, pits below ground surface, or other sources of contamination;

Fig. 6. Dug well with windlass[a]



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?

[a] After Rajagopalan & Shiffman (*30*).

(9) wellheads, well casings, pumps, pumping machinery, exposed suction pipes, or valve boxes connected to suction pipes located in pits extending below the ground surface;

(10) manufacturing, industrial, or agricultural plant wastes discharged or spilled on watersheds or into underground strata causing contamination of groundwater supplies;

(11) failure to disinfect new wells and springs;

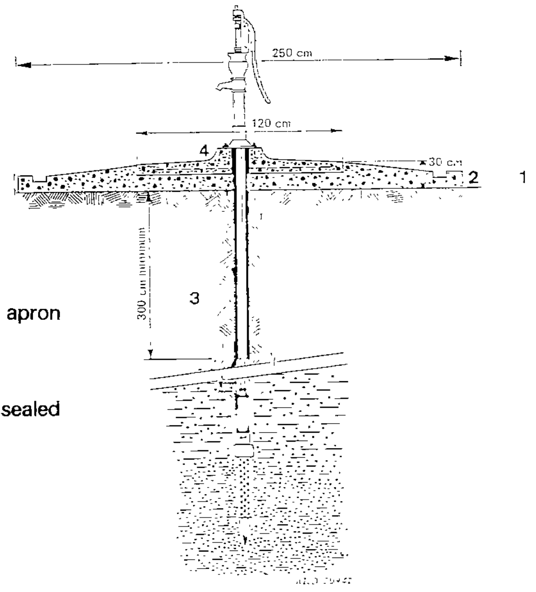
(12) failure to provide sanitary facilities for construction workers;

(13) pump not self-priming; unsafe water used for priming.

Surface water sources and treatment

(1) Excessive raw water pollution in relation to extent of treatment provided;

Fig. 7. Tube well[a]

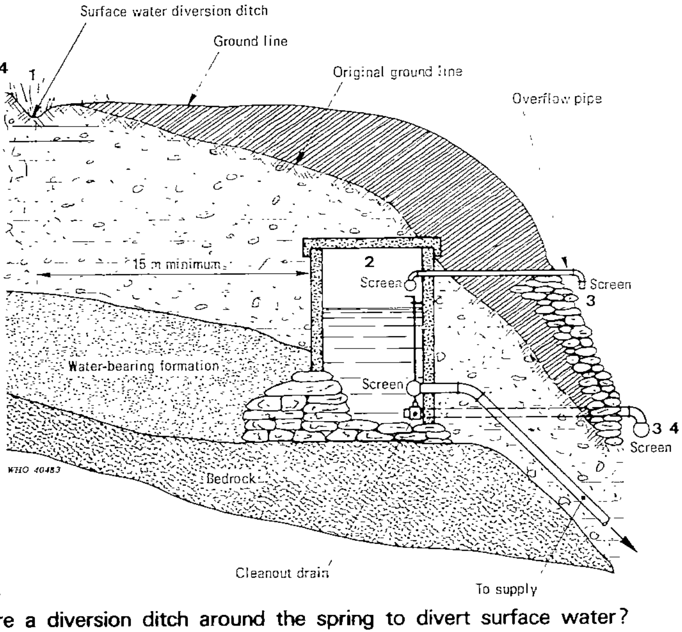


Check list

1. Is the nearby area free from liquid wastes and privies?
2. Is there a watertight concrete apron and is drainage provided?
3. Is there watertight tubing for 3 m below ground level?
4. Is the eduction pipe to pump sealed in apron at exit?

[a] After Rajagopalan & Shiffman (*30*).

Fig. 8. Protected spring source[a]

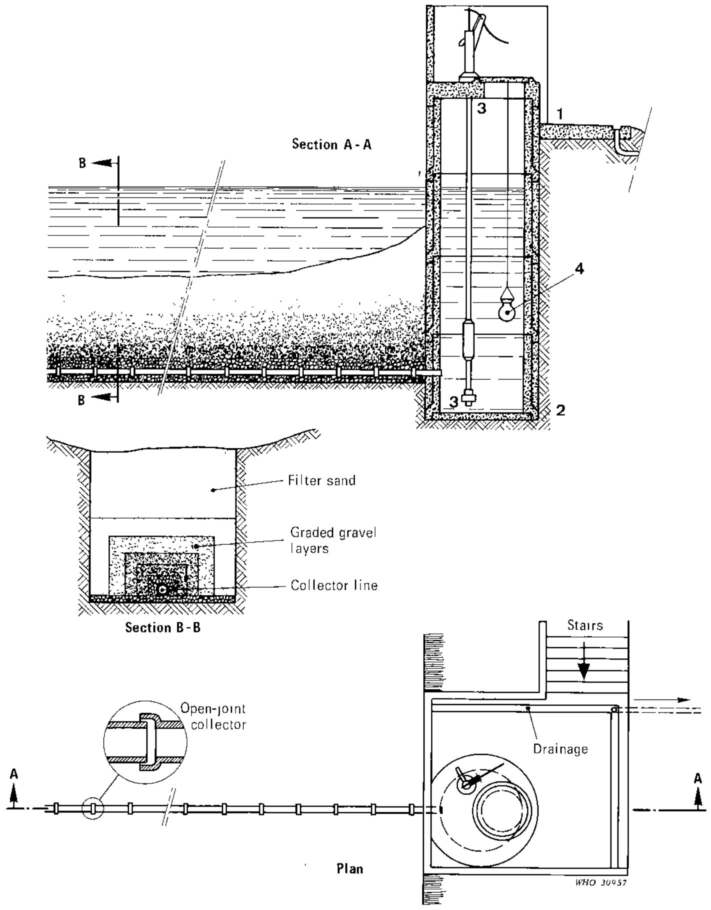


Check list

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?

[a] After Rajagopalan & Shiffman (*30*).

Fig. 9. Infiltration gallery in village pond[a]



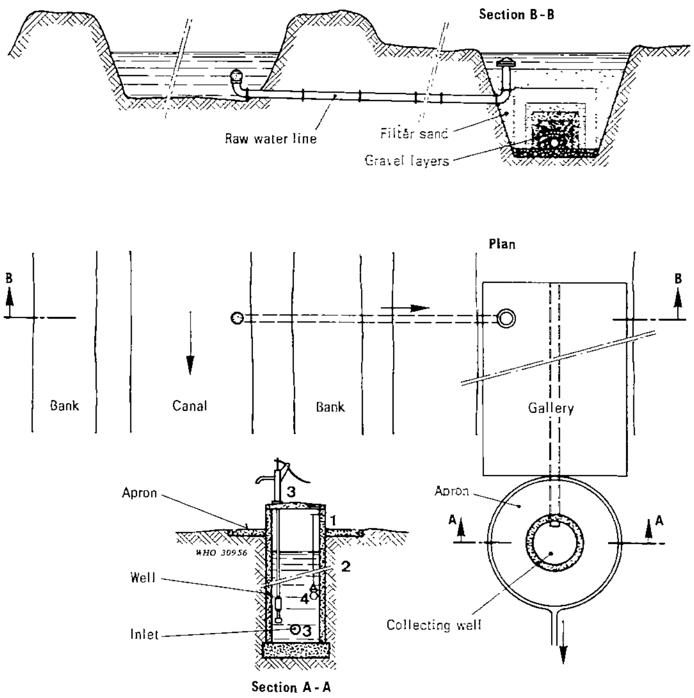
Check list
1. Does the collecting well extend 1 m above ground?
2. Is the collecting well sealed watertight throughout?
3. Are the inlet and outlet pipes well sealed in place?
4. Is the water chlorinated?

[a] After Rajagopalan & Shiffman (*30*).

(2) 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;

(3) no restrictions on recreational use of streams and reservoirs on marginal land in the local catchment area;

Fig. 10. Infiltration gallery for canal[a]



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?

[a] After Rajagopalan & Shiffman (*30*).

(4) inadequate sanitary facilities and control of contamination at reservoirs used for recreational purposes;

(5) improper location of intakes with respect to bottom of reservoir and current or to inlets for surface drainage water;

(6) intakes exposed and accessible to trespassers;

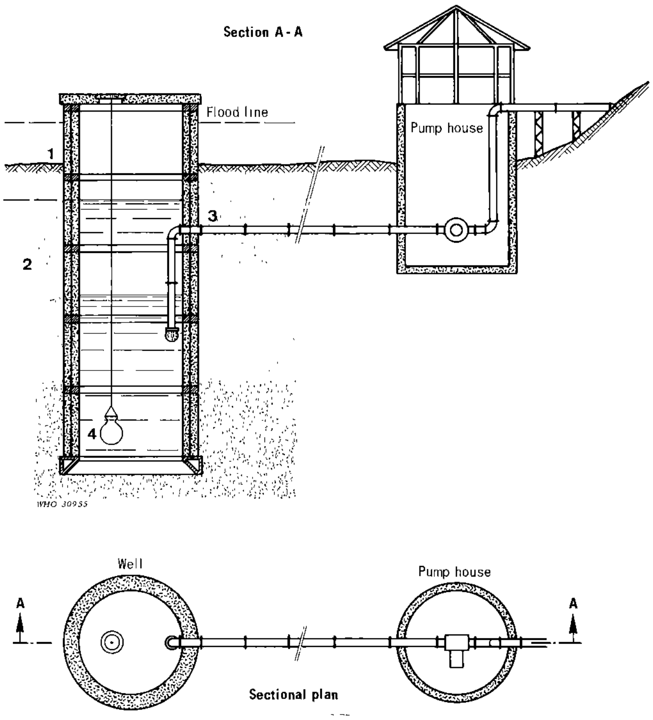
(7) improper location of water treatment plant or inadequate protection against flood waters;

(8) lack of competent supervision and operation, faulty maintenance, or lack of adequate laboratory control;

(9) lack of proper chlorination equipment, deficiency in, or unreliability of, equipment and lack of control; failure to maintain proper chlorine residuals in the treated water at all times;

(10) lack of suitable devices for measuring and recording volumes of

Fig. 11. Infiltration well in river bed, and pump house[a]



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?

[a] After Rajagopalan & Shiffman

water treated and for maintaining continuity of coagulant and chlorine dosages; deficient retention periods in settling basins or inadequate filtration and backwashing capacity;

(11) existence of cross-connexions, 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;

(12) by-pass connexions for raw water or partially treated water, permitting such waters to be discharged into the distribution system;

(13) lack of reserve capacity in treatment works, necessitating excessive overloading or occasional by-passing of units;

(14) lack of sanitary latrines and washing facilities for waterworks personnel;

(15) contamination by infected employees or by unauthorized visitors;

(16) inadequate arrangements for cleaning and draining floors, tanks, aprons, etc.;

(17) lack of suitable protection for purified water; storage capacity less than that required for safety.

Distribution

(1) 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 pressures; lack of provision for maintaining continuity of pumping service under all conditions;

(2) repumping on consumer premises when pressure is low, causing negative head;

(3) existence of cross-connexions between the primary supply and a secondary supply of questionable safety (see Annex 5);

(4) 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-connexions;

(5) lack of, or inadequate, enforcement of plumbing regulations and/or ordinances designed to protect the water supply against the possibility of backflow from plumbing fixtures or from mechanical equipment supplied with water from the public water supply;

(6) connexion of new pipelines to the system without prior disinfection of pipes;

(7) unauthorized operation of water supply facilities by persons other than waterworks employees—private plumbers, for example;

(8) existence of leaky pipes in the distribution system;

(9) improper location of water pipes in relation to sewers and storm-water drains;

(10) return to the system of water used for cooling purposes;

(11) connexions to sewers and sewer-flushing chambers, and improperly located blow-offs in the distribution system;

(12) 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;

(13) 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;

(14) poorly drained and protected street fountains;

(15) defective service reservoirs.

Annex 5

CROSS-CONNEXIONS AND BACK-SIPHONAGE

Introduction

A cross-connexion is a hydraulic linkage permanently or temporarily connecting a source of pollution with pipes carrying drinking-water. The contaminant enters the drinking-water system when hydraulic pressure from the polluted source exceeds the hydraulic pressure of the drinking-water. This may be the result of back-siphonage or backflow. Essentially, it is simply a detrimental reversal of flow direction due to hydraulic pressure changes produced by a variety of circumstances.

Public health officials have long been concerned about cross-connexions and backflow in drinking-water distribution and plumbing

Fig. 12. Air gap protection of water supply. (*a*) Sanitary fixtures; (*b*) swimming pools and storage tanks; (*c*) booster pumping for multistorey buildings and industrial processes

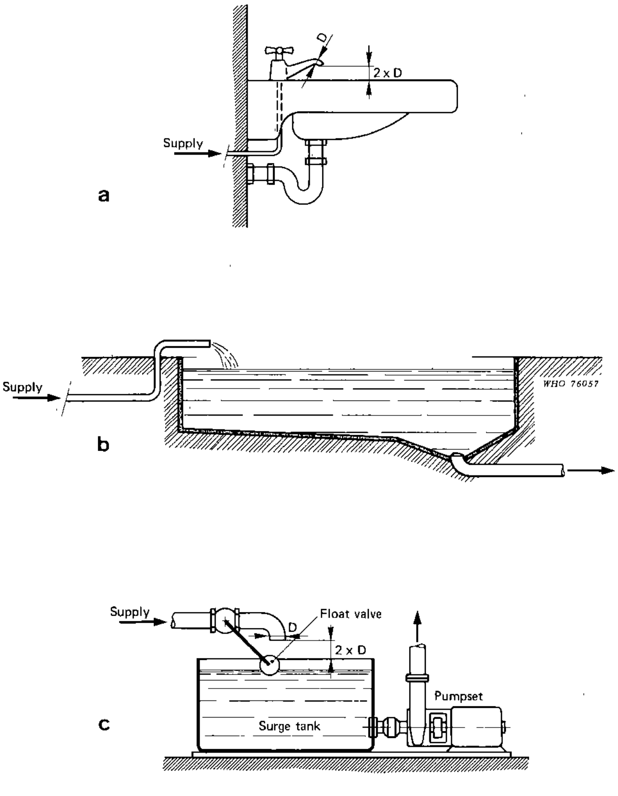
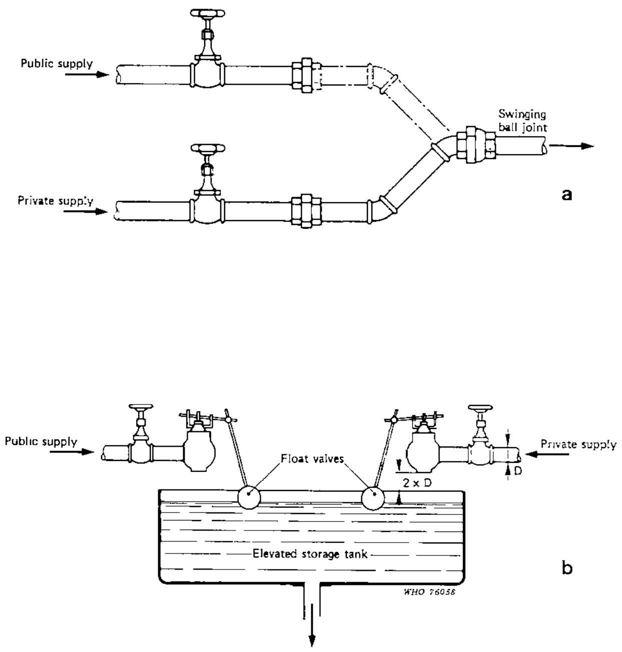


Fig. 13. Physical separation of dual drinking-water supplies. (*a*) Swing connexion; (*b*) air gap



systems. The risks of cross-connexions and contamination of potable water are always present. For example, in Chicago, USA, during the World Fair in 1933 defective and improperly designed plumbing permitted the contamination of drinking-water in several hotels. As a result, over 1400 people contracted amoebic dysentery and there were 98 deaths. Epidemics resulting from contamination introduced into public water supplies through cross-connexions demonstrate clearly the responsibility of public health officials and water purveyors for exercising control over public water distribution systems and all plumbing systems connected to them. This responsibility includes advising and instructing those installing plumbing in the recognition and elimination of cross-connexions.

Control

The control of backflow requires the removal of the two essential factors: (1) the physical link and (2) the cause of the reversed pressure gradient. The removal of the link, or cross-connexion, is a positive means of preventing backflow.

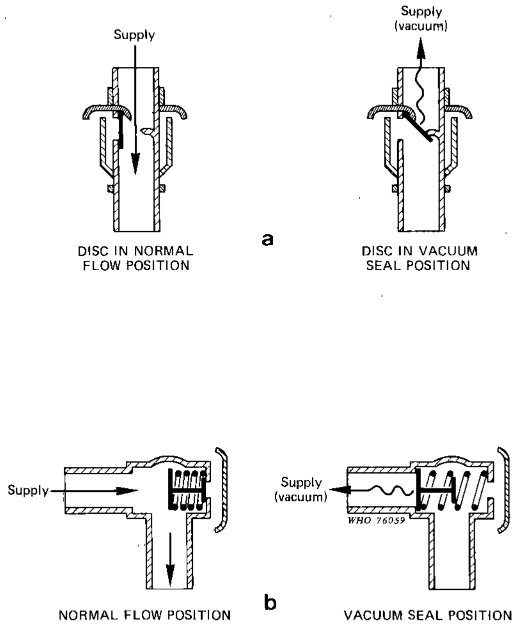
The only absolute means of eliminating the physical link is through the use of a vertical air gap (*36*) as illustrated in Fig. 12. Air gaps should be used whenever possible, and where they are used they must not be by-passed. The supply inlet to plumbing or industrial fixtures should be terminated above flood level rim by a distance equal to at least twice the effective opening of the inlet. There should be no provision for extending the inlet below the flood level rim. If the end of the supply pipe is threaded or serrated to permit the connexion of a hose, a properly installed vacuum breaker should also be provided. If an air gap separation is provided at each fixture, complete protection will be provided within the building as well as to the public water supply.

Under certain circumstances air gap separation, or an approved alternative (written approval should be required), should be provided at the point where the water service enters the building or factory. These circumstances include the following:

(1) when, as is often the case in public water systems operating under low pressure or intermittently, the user installs his own pump for raising the pressure or for extracting more water from the system;

(2) when the user boosts the pressure by pumping water for distribution or elevated storage in large or "high-rise" buildings;

Fig. 14. Vacuum breaker protection of supply to plumbing or industrial fixtures. (*a*) Non-pressure type vacuum breaker, installed *after* fixture valve; (*b*) pressure type vacuum breaker, installed *before* fixture valve



(3) when the user maintains a separate source of potable water, such as a well, that is interconnected to the public supply but is not under surveillance by the public water authority;

(4) when the user maintains a separate dual water system for industrial use or irrigation purposes that is interconnected to the drinking-water system for "emergency" or other occasional use;

(5) when the user operates industrial processes with risks of backflow or back-siphonage of contaminated or toxic substances into the water.

Fig. 12c shows how an air gap may be provided at the service entrance. Fig. 13b shows how dual supplies may be physically separated by using an air gap where delivery of the drinking-water is made to an elevated tank that may also receive water from non-regulated sources. When public drinking-water is used only occasionally in industries having separate supplies the method shown in Fig. 13a is sometimes used. This is easily subverted by human error or negligence.

A fundamental factor in back-siphonage is vacuum or negative pressure. If atmospheric pressure is admitted to a piping system between a source of pollution and the origin of a vacuum, back-siphonage will be prevented. This is the function of a vacuum breaker. Because a vacuum may be created at numerous places in a piping system, a vacuum breaker must be located as near as possible to the fixture from which contamination is anticipated. The position of a vacuum breaker must be sufficiently high above the fixture flood level rim to prevent

Fig. 15. Backflow prevention devices. (*a*) Reduced pressure backflow preventer in line; (*b*) double check–double gate valves in line

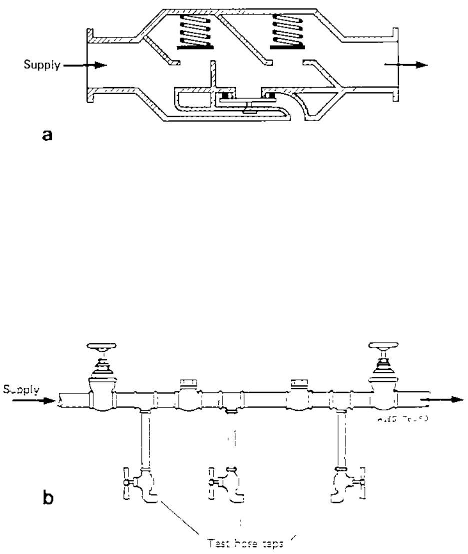
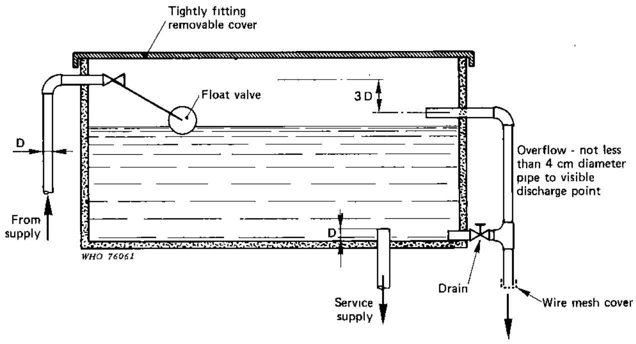


Fig. 16. Household roof tank or storage cistern



flooding or submergence of the vacuum breaker or the occurrence of back pressure. Pressure and non-pressure type vacuum breakers are shown in Fig. 14; these are designed to prevent back-siphonage only and cannot be installed where back pressures are likely to occur.

In situations where it would be extremely difficult to provide a physical break between two systems, and where back pressures can be expected, a reduced pressure backflow preventer, the principle of which is shown in Fig. 15a, can be used. This device consists of two hydraulically or mechanically loaded pressure reducing check valves with a pressure regulated relief valve located between the two check valves. These devices are expensive and often must be imported. A more common method of backflow prevention is the double gate–double check valve installation shown in Fig. 15b; this is, however, not completely reliable.

Prevention is obviously preferable to correction at a later stage, and places where cross-connexions are inexcusable are at the water treatment plant and in water and wastewater installations inside buildings. An example of a well designed household storage tank is shown in Fig. 16.

Investigation of cross-connexions

Cross-connexions may be found in any place where drinking-water is provided and where there are sewers or wastes on the premises and /or separate water supplies from wells, rivers, canals, cisterns, or other sources. Surface wells are peculiarly subject to pollution, and even deep wells may become polluted overnight.

The following potential cross-connexions should be prevented during the design stage (*35*):

(1) no cross-connexion should be permitted to exist in a filtration plant between any conduit carrying filtered or post-chlorinated water and another conduit carrying raw water or water in any earlier stage of treatment;

(2) conduits carrying raw water, or any water in an earlier stage of treatment, should not be located directly above, or adjacent to, or around, another conduit or basin carrying finished water when there is a single, common wall or partition between them;

(3) rewash or filter-to-waste conduits should not be directly connected to any drainage conduit but should be protected by a suitable one-way air gap delivery connexion to ensure that no backflow can occur under any circumstances.

Other common locations or sources of cross-connexions or back-siphonage include:

(1) leaks in distribution systems that are often subject to low pressure or to intermittent operation, especially in mains and services near sewers: the suction side of booster pumps is a particularly frequent location;

(2) yard hydrants arranged so that polluted ground or surface water can drain into the valve meter pit; pit taps in underground chambers subject to flooding, especially at railway stations, docks, and other public facilities, are often incriminated;

(3) dual water systems where one system is intended for firefighting, industrial processes or other applications but not for supplying drinking-water;

(4) water supply for pump priming or sealing rings, especially in water and sewage plants;

(5) pumpage pits with drains into cesspools or other sources of pollution;

(6) automatic water-supplied, siphon-flush tanks with an inlet below the waterline, including public sewer flush tanks;

(7) improperly designed or installed water closets, tubs, wash basins, and sinks;

(8) swimming pools having water supply inlets below the overflow line or a physical connexion between a potable water supply and the circulating mains;

(9) hospital appliances generally, including sterilizers, condensers, filters, stills, aspirators, etc.—gauge glasses and connexions of stills sometimes remain polluted and the entire contents of a still may be contaminated;

(10) floor drains with water-flush connexions;

(11) industrial vats, tanks, etc., of any description that have an inverted water supply connexion or a water supply connexion below the top of the spill rim, or in which a hose filler is used;

(12) process appliances supplied with industrial water *via* direct water connexions but lacking adequate air gaps;

(13) rubber hoses with hand controls or self-closing faucets attached, as used in baths, industrial vats, tanneries, etc.;

(14) buildings where sewage is pumped on the premises;

(15) tall buildings;

(16) waterfront property;

(17) in general, any type of water supply connexion that permits the return of used water into the water supply system by drainage, siphonage, or force.

Administration of a cross-connexion control programme

Public health personnel, waterworks officials, plumbing inspectors, building supervisors, plumbing installers, and maintenance personnel all share to some degree the responsibility for protecting the health and safety of the public against contaminated water. These responsibilities include ensuring correct sanitary design and installation practices in piping systems and plumbing fixtures and encouraging, as well as assisting in, the training of persons responsible for the installation and maintenance of water systems. Officials responsible for the inspection of plumbing installations should ensure the maximum protection against backflow consistent with good judgement and public safety. Plumbing installers and maintenance personnel should observe and avoid or eliminate possibilities for backflow and be diligent in adhering to plumbing codes and ordinances.

The successful promotion of a cross-connexion and backflow connexion control programme in a municipality will depend on legal authority for conducting such a programme. Where a nation or community has adopted a plumbing code the provisions of the code should apply to backflow and cross-connexions. It then remains to provide an ordinance to establish a programme of inspection for the elimination of backflow and cross-connexions within the community. Frequently, the health or water authority already has a mandate for such a programme. A cross-connexion control ordinance should consist of at least three basic elements:

(1) authority for establishing a programme;

(2) technical provisions relating to the elimination of backflow and cross-connexions;

(3) provisions for penalties for violation of the ordinance.

At the present time few developing countries have an effective cross-connexion control programme; in part, this is tacit recognition of the fact that cross-connexion surveys of consumer premises do not protect as many people per man-hour spent on surveillance as do sanitary surveys of, say, the raw water source or the treatment plant. However, cross-connexions are an important hazard to health and the following measures are suggested, in order of priority, as resources and manpower become more available.

(1) Surveys of sources;

(2) surveys of treatment plants and review of proposed construction work;

(3) adoption of regulations for providing service;

(4) surveys of distribution systems;

(5) adoption of standards for plumbing fixtures;

(6) adoption of a plumbing code;

(7) adoption of plumber certification or licensing;

(8) adoption of a cross-connexion ordinance;

(9) staff training;

(10) implementation of a formal cross-connexion control programme.

Annex 6

MUNICIPAL WATER SUPPLY SANITARY SURVEY; SAMPLE REPORTING FORM

Survey of: source ☐
treatment ☐
distribution ☐

Date of survey ☐ day ☐ month ☐ year

1. Name of supply ....
2. Owned by ....
3. Location (attach sketch if necessary) ....
....
4. Mail address .... street or P.O. Box ... city ... state or province
5. Person in charge ....
6. Population served: by house connexions ☐
by standposts or public hydrants ☐
Population unserved by public water system ☐

Water demand	Present (from plant records)	Future (10-year estimate)	Unknown
A. Average day	☐	☐	☐
B. Maximum day	☐	☐	☐
C. Maximum month	☐	☐	☐

Water use has been restricted ☐ times for a total of ☐ days during the past year.

7. Laboratory control: yes ☐ no ☐
   A. Bacteriological (distribution system): yes ☐ no ☐
      (*a*) Minimum number of samples per month recommended by surveillance agency ☐
      (*b*) Average number of samples taken per month during last 12 months ☐
      not known ☐
      (*c*) Range: number of samples taken in lowest month ☐
      in highest month ☐

(*d*) Number of months during last 12 months in which standards were not met for:

(i) water quality ☐ not known ☐

(ii) number of samples collected ☐ not known ☐

No samples collected ☐

(*e*) Samples are representative of distribution system (judge from map of distribution system):

yes ☐ no ☐ no map ☐

(*f*) Sampling is repeated when bacteriological tests are presumptive for coliform bacteria (should be determined from plant records, not from oral questioning):

yes ☐ no ☐ not known ☐

(*g*) Test results requiring check samples are immediately reported to the water system management by telephone or personal contact:

yes ☐ no ☐ not known ☐

(*h* The laboratory is certified: yes ☐ no ☐

No certification programme ☐

(*i*) Samples are generally received by laboratory within 24 hours:

yes ☐ no ☐ not known ☐

B. Chemical analysis: yes ☐ no ☐

(*a*) Date of last chemical analysis ☐ day ☐ month ☐ year

(*b*) Analysed by: waterworks ☐

surveillance agency ☐

other agency ☐ .... (identify)

(*c*) Tests run for operational control

Test	*Yes*	*No*	*Frequency*
alkalinity	☐	☐	☐
aluminium	☐	☐	☐
chloride	☐	☐	☐
chlorine residual	☐	☐	☐
colour	☐	☐	☐
fluoride	☐	☐	☐
hardness	☐	☐	☐
iron	☐	☐	☐
jar tests	☐	☐	☐
manganese	☐	☐	☐

	Yes	*No*	*Frequency*
pH	☐	☐	☐
taste and odour	☐	☐	☐
turbidity	☐	☐	☐
others (list)	☐	☐	☐
	☐	☐	☐
	☐	☐	☐

8. Sanitary survey

A. Date of last survey (not this one): ☐ ☐ ☐
day month

B. Made by: waterworks ☐, surveillance agency ☐,
local health department ☐, consultant ☐,
other agency ☐ ....
(identify)

C. Facilities surveyed: source ☐, transmission ☐,
treatment ☐, storage ☐, distribution ☐,
other facilities ☐ ....
(identify)

9. Facilities and operations (describe deficiencies on back of this sheet of paper)

	Yes	*No*
A. Common walls or partitions exist between treated and untreated water	☐	☐
B. Interconnexions to other "systems" are	☐	☐
(*a*) of known acceptable quality	☐	☐
(*b*) of unknown quality	☐	☐
(i) with protection	☐	☐
(ii) without protection	☐	☐
C. There is a cross-connexion control programme	☐	☐
(*a*) for new construction work only	☐	☐
(*b*) for continuous re-inspection	☐	☐
D. Finished water reservoirs are properly covered	☐	☐
E. There is a detectable chlorine residual in distant parts of the distribution system	☐	☐
F. The treatment plant can be by-passed	☐	☐
G. New construction work and repairs are disinfected prior to being placed in service	☐	☐

H. There are areas of low pressure (i.e., les than 138 kPa or 1.4 kgf/cm^2) in the distribution system: yes ☐ no ☐

I. Distribution pressure is maintained at all times: yes ☐ no ☐

J. Operating problems most often encountered:
taste and odour ☐, turbidity in treated water ☐,
colour ☐, short filter runs, ☐, other problems ☐ ....
(identify)

K. Chlorination process was interrupted ☐ times in the last 12 months
Interruptions were due to chlorinator failures ☐,
feedwater pump failure ☐, changing cylinders ☐,
power failure ☐, lack of chlorine ☐,
lack of hypochlorite ☐, other failures ☐ ....
(identify)

L. Chlorine supply on hand sufficient for ☐ days

M. Chlorine delivery time is about ☐ days

N. Chlorine comparators on hand: yes ☐ no ☐

10. Source, treatment, and distribution (describe deficiencies on back of this sheet of paper)

A. Are the following adequate?

		Yes	*No*
(*a*)	source with respect to:		
(i)	quantity	☐	☐
(ii)	bacteriological quality[a]	☐	☐
(iii)	chemical quality[a]	☐	☐
(iv)	physical quality[a]	☐	☐
(v)	adequate protection	☐	☐
(*b*)	transmission of raw water	☐	☐
(*c*)	sampling of raw water for:		
(i)	bacteriological contamination	☐	☐
(ii)	chemical contamination	☐	☐
(*d*)	treatment with respect to:		
(i)	aeration	☐	☐
(ii)	chemical mixing	☐	☐
(iii)	chemical feed	☐	☐
(iv)	flocculation	☐	☐
(v)	sedimentation	☐	☐

---

[a] As defined in the drinking-water standards.

	Yes	No
(vi) filtration (rapid ☐ or slow ☐)	☐	☐
(vii) disinfection	☐	☐
(*e*) distribution with respect to:		
(i) storage	☐	☐
(ii) booster chlorination	☐	☐
(iii) residual chlorine	☐	☐
(iv) booster pumping	☐	☐
(v) pressure	☐	☐
(vi) continuity of supply	☐	☐
(vii) leakage	☐	☐
(*f*) maintenance:		
(i) source	☐	☐
(ii) treatment	☐	☐
(iii) distribution	☐	☐
(*g*) records for:		
(i) disinfection	☐	☐
(ii) filter runs	☐	☐
(iii) chemical consumption	☐	☐
(iv) operational control tests	☐	☐
(v) bacteriological examinations	☐	☐
(vi) residual chlorine	☐	☐
(*h*) cross-connexion control:		
(i) ordinance	☐	☐
(ii) programme implementation	☐	☐
(iii) progress	☐	☐

B. During the past 3 years raw water quality has improved ☐, deteriorated ☐, remained the same ☐

C. During the past 3 years treated water quality has improved ☐, deteriorated ☐, remained the same ☐

D. During the past 3 years distributed water quality has improved ☐, deteriorated ☐, remained the same ☐

11. Personnel

A. Water treatment plant operators

(*a*) highest level of formal education: university ☐,
technical institute ☐, secondary school ☐,
trade school ☐, other training ☐ ....
(identify)

(*b*) level of formal training in water treatment: university ☐,
technical institute ☐, trade school ☐, short courses ☐

(*c*) length of time in formal training: ☐ weeks

(*d*) length of time in present plant: ☐ years

(*e*) total experience in water treatment: ☐ years

(*f*) **operator is a full-time employee:** yes ☐ no ☐

(*g*) **present staff is adequate**

(i) in number: yes ☐ no ☐

(ii) in quality: yes ☐ no ☐

(*h*) **budget is adequate:** yes ☐ no ☐

(*i*) **management is adequate:** yes ☐ no ☐

B. Operator's major complaint ....

....

....

C. Management's most frequent complaint ....

....

....

D. Most frequent consumer complaint received by the water supply system ....

....

E. Most frequent consumer complaint received by the surveillance agency ....

....

12. Waterborne disease in community (information to be obtained from health officials)

A. Last outbreak of cholera: ☐ year

B. Morbidity rates, if available, for year of most recent available data:

Disease	Most recent year ☐		Previous year ☐	
	Local rate	National rate	Local rate	National rate
Cholera Typhoid fever Gastroenteritis, diarrhoea, etc.				

13. ***Mandatory corrections of deficiencies*** **in order of priority (attach additional sheets if necessary; number of additional sheets ☐)**

14. Suggested improvements (attach additional sheets if needed)

Survey made by: ....
Printed name and signature

Date: ☐ ☐ ☐
day month year

Title: ....

Agency: ....

Notification and acknowledged by: ....
Printed name and signature

Date. ☐ ☐ ☐
day month year

Title: ....

Agency: ....

FOR OFFICE USE ONLY

Remedial action completed ....

Date: ☐ ☐ ☐
day month year

Verified by: ....
printed name and signature

Remedial action NOT completed as of ☐ ☐ ☐
day month year

Following measures taken: ....

....

....

Verified by: ....

Annex 7

CHECKLIST FOR COLLECTION OF BACTERIOLOGICAL SAMPLES[a]

Sampling

☐ Representative points throughout distribution system

☐ Location and frequency of sampling adequate

☐ Minimum monthly number of samples adequate for population

Number of samples per month required for this system ☐

☐ Repetitive samples from points with unsatisfactory history

☐ Proportionately more samples from critical parts of distribution system subject to higher risks

☐ Samples from disinfected repairs or new construction work

Sample bottles

☐ Samples collected in sterilized glass bottles provided with ground-glass stoppers or metal screw caps

☐ Stopper and neck of the bottle protected by a paper/parchment cover or aluminium foil

☐ Sampling bottle unopened till sampling, stopper replaced immediately after sampling

Collection procedure

☐ Volume of water necessary for all tests

☐ Minimum sample not less than 100 millilitres

☐ Ample air space left in bottle to facilitate mixing

☐ Representative samples collected without incurring contamination

☐ Tap samples collected from taps connected directly to water main by service pipe

☐ Sampling not collected from taps connected to storage tanks

☐ Taps allowed to waste water until service lines have been cleared

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[a] In chlorinated systems, samples should also be analysed immediately for residual chlorine.

☐ River, stream, lake, or reservoir samples collected by plunging opened bottles neck downwards below the surface

☐ Samples collected with mouth end of bottle facing into current (or away from hand)

☐ Pump allowed to waste water for 5 minutes before samples are taken

☐ Prompt identification of samples in legible, indelible writing

☐ Samples accompanied by complete and accurate data

Dechlorination

☐ Sodium thiosulfate used for dechlorination

☐ Sodium thiosulfate added before sterilization of bottle

☐ Thiosulfate concentration approximately 100 milligrams per litre

Transportation and storage

☐ Temperature maintained as close as possible to the water temperature at time of collection

☐ Sample examined as soon as possible after collection

☐ Examination within 1 hour after collection recommended

☐ Time between collection and examination not more than 30 hours

☐ Established field procedure where time exceeds 24 hours

☐ Time and temperature of storage recorded

☐ Established procedure for transporting samples to laboratory

☐ Established procedure for transporting sterile sample bottles to field

Annex 8

METHODS OF ANALYSIS

GENERAL

Numerous authoritative, detailed and comprehensive treatises on the physical, chemical, bacteriological, biological, and radiological examination of drinking-waters are readily available (see references *10, 17–25*). "Simplified" procedures are also available (*42*). 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 here. The two parameters are residual chlorine concentration and number of coliform bacteria, an index of possible contamination of the water by faecal matter. As described in Chapter 7, residual chlorine concentration can be used as an index of bacterial contamination (see also reference *43*).

RESIDUAL CHLORINE CONCENTRATION

Comparator test kits

Elaborate techniques, amperometric titration, for example, are available for measuring chlorine concentration with high precision. However, field techniques using colorimetric procedures are sufficiently accurate for control of chlorine dosage.

An inexpensive measuring technique, suitable for both field and plant use, employs colour comparison test kits—often called pocket comparators or chloroscopes. These kits use permanent standards, either small coloured glasses, generally mounted on a disc, or sealed glass ampoules of coloured liquid that can be compared with the sample in a similar, open ampoule. The standards should be protected from light, heat, dirt, fungal growth, spills, and careless handling.

The disc comparator consists of a plastic box with an eyepiece in front and a frosted glass in the rear. Behind the eyepiece is a place for attaching the rotating colour disc. Between the disc and the frosted glass is a divided compartment for two cells holding a sample of the untreated water sample and a sample of the water treated with a reagent. The untreated water sample is positioned on the same side as, and in line with, the rotating coloured glasses. The other side of the compartment is reserved for the sample in which a colour has been developed chemically. The concentration of the substance to be measured is estimated visually by looking through the eyepiece of the comparator and matching the developed colour with the permanent colours on the disc. The colour disc can easily be removed from the comparator and replaced by a different disc for another determination. Thus, one comparator kit can serve for a number of separate determinations including pH, colour, iron, and manganese. A common error is to confuse the colour disc for one test, say, chlorine, with that for another test.

Test kits produce rapid, acceptable, and consistent results in the hands of individuals who have received a minimum of training. Their portability makes them useful for checking operations in the field.

Ortho-tolidine test[a]

Ortho-tolidine reacts with both free and combined chlorine in an acid solution to give a yellow coloration. Ortho-tolidine reacts with free chlorine instantaneously but reacts more slowly with combined chlorine. The "flash" method is based on this fact, and if the test is read within 10 seconds after the addition of the reagent only free residual chlorine will be estimated.

Ortho-tolidine/arsenite test (OTA)

The errors caused by the presence of interfering substances such as nitrites, iron, and manganese, all of which produce a yellow colour with *o*-tolidine, are overcome in the OTA method. Thus this method allows more accurate differentiation between free residual chlorine and combined residual chlorine. The principle of the method is that the colour produced by the reaction of residual chlorine with *o*-tolidine is not formed in the presence of sodium arsenite, whereas the colour produced by the interfering agents persists. The test is carried out as follows (*44*).

(*a*) Take 3 tubes graduated to hold 10 millilitres (ml); label them "A", "B", and "O-T";

(*b*) To tube A add 0.5 ml of *o*-tolidine solution, then add 10 ml of the water sample and mix; add 0.5 ml of sodium arsenite solution within 5 seconds; mix and compare the colour with the standards as rapidly as possible; record the reading (A) in milligrams per litre.

(*c*) To tube B add 0.5 ml of arsenite solution, then add 10 ml of the water sample, mix quickly, and immediately add *o*-tolidine solution; mix and compare the colour with the standards as rapidly as possible, and record the reading (B_1) in milligrams per litre.

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[a] Ortho-tolidine compounds are toxic and should be handled with caution.

(*d*) Retain the contents of the tube and compare again with the standards after exactly 5 minutes; record the reading (B_2) in milligrams per litre.

(*e*) To tube O-T add 0.5 ml of *o*-tolidine reagent and then add 10 ml of the water sample; mix and allow to stand for exactly 5 minutes; compare the colour with the standards; record the reading (O-T) in milligrams per litre.

(*f*) From the above readings, calculate the different values as follows:

total residual chlorine = $\text{O-T} - B_2$,
free residual chlorine = $A - B_1$,
combined residual chlorine = $(\text{O-T} - B_2) - (A - B_1)$.

Preparation and storage of o-tolidine reagents (18)

Ortho-tolidine solution should not be stored for more than 6 months as a precaution against discoloration or precipitation due to occasional exposure to high temperatures or sunlight and consequent errors in analysis.

To prepare *o*-tolidine reagent, dissolve 1.35 g of *o*-tolidine dihydrochloride in 500 ml of distilled water. Add this solution with constant stirring to a mixture of 350 ml of distilled water and 150 ml of concentrated hydrochloric acid.[a] Do not use *o*-tolidine base in preparing this reagent.

Store the *o*-tolidine solution in brown glass bottles or in the dark. Protect at all times from direct sunlight. Use for not longer than 6 months. Prevent contact between the solution and rubber. Store the solution at room temperature, avoiding extremes of temperature.

Ortho-tolidine is highly dangerous to health. Never use a mouth pipette for dispensing these reagents. Avoid inhalation or contact with the skin.

To prepare sodium arsenite solution, dissolve 5.0 g of $NaAsO_2$ in distilled water and dilute to 1 litre. Sodium arsenite is also toxic and care should be taken not to ingest any of the solution.

DPD method for residual chlorine

Another method suitable for both laboratory and field use was developed by Palin (*18, 48*); it uses *N,N*-diethyl-para-phenylenediamine (DPD) in the ferrous titrimetric method in place of neutral ortho-tolidine. In the absence of iodine free available chlorine reacts instantly

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[a] The concentration of the acid must be such that it will produce a pH of 1.3 or lower even if the sample has up to 1 000 mg of alkalinity.

with DPD to produce a red coloration. The colours produced are more stable than those produced by ortho-tolidine. Decolorization by standard ferrous ammonium sulfate (FAS) solution is instantaneous in the titrimetric procedure (PDP–FAS). In the colorimetric method (DPD) the standard colours are prepared by use of a standard potassium permanganate solution.

Reagents. The following reagents are required.

(1) Phosphate buffer solution. Dissolve 24 g of anhydrous disodium hydrogen phosphate and 46 g of anhydrous potassium dihydrogen phosphate in distilled water. Add 100 ml of 0.8 % EDTA sodium salt[a] solution, and make up to litre. Add 20 mg of mercuric chloride to prevent growth of moulds.

(2) Diethyl-*p*-phenylene diamine (DPD) solution (indicator). Dissolve 1 g of DPD oxalate, or 1.5 g of DPD sulfate, in chlorine-free distilled water to which 8 ml of sulfuric acid (1 part of distilled water to 3 parts of acid) and 25 ml of 0.8 % EDTA solution have been added. Make up to 1 litre, store in an amber-coloured glass-stoppered bottle, and discard when discoloured. The buffer and indicator are commercially available as a combined reagent in stable powder form.

(3) Potassium iodide crystals.

(4) Standard ferrous ammonium sulfate solution. Dissolve 1.106 g of Mohr's salt, $Fe(NH_4)_2(SO_4)_2.6H_2O$, in distilled water containing 1 ml of sulfuric acid (1 part of distilled water to 3 parts of acid) and make up to 1 litre with freshly boiled and cooled distilled water. This is a primary standard and may be used for 1 month. Potassium dichromate may be used to check the titre. The FAS solution is equivalent to 0.100 mg of Cl^- per 100 ml.

Procedure. Place 5 ml each of buffer solution and DPD solution in the titration flask and mix (or use about 0.5 g of DPD powder); add 100 ml of the water sample and mix again.

(*a*) Free available chlorine. Titrate rapidly with standard FAS solution until the red colour is discharged (amount of FAS solution required (millilitres) = reading A).

(*b*) Combined available chlorine. Add several crystals of potassium iodide (about 1 g) to the same sample and allow to stand for 2 minutes, then continue titration with standard FAS solution until the red colour is again discharged (amount of FAS solution required (millilitres) = reading B).

Then:

free available chlorine (mg/litre) = A,
combined available chlorine (mg/litre) = B,
total available chlorine (mg/litre) = A+B.

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[a] Disodium ethylenediaminetetraacetate dihydrate, also called (ethylenedinitrilo)tetraacetic acid sodium salt.

The DPD test can also be used to differentiate between monochloramines and dichloramines, as well as to ascertain the presence of nitrogen trichloride. The test can be conveniently carried out in the field, and kits using the colorimetric method are available commercially. Reagents for free, combined, and total chlorine determinations are also supplied in tablet form. Instructions for using these kits are available from manufacturers.

Both the ortho-tolidine and DPD methods are subject to interference, and special tests are needed to correct such errors when they are large enough to be of concern. Overall, the DPD method is less sensitive to interference.

Other field tests for chlorine

Other promising field tests for free chlorine in water using syringaldazine, methyl orange, and stabilized neutral *o*-tolidine have been developed in recent years (*45–47*). Surveillance programmes that have opportunities for research and development may find some of these new developments worthy of investigation.

MEMBRANE-FILTER TEST FOR COLIFORM BACTERIA

Introduction

The traditional, proven test for coliform bacteria is the multiple-tube fermentation test. A newer test using membrane filters is an acceptable alternative procedure. The membrane-filter test is convenient for field use and requires less time to produce results. An abbreviated test procedure is outlined below. More complete descriptions of the procedures (*17, 18*) and the manufacturers' instructions should be consulted before use.

Special apparatus

In addition to the usual bacteriological laboratory equipment—autoclaves, incubators, balances, glassware, etc.—membrane-filtration requires the following:

(1) a vacuum source of at least 50 kPa (0.5 kgf/cm^2) differential pressure (water aspirators, electric pumps, and bicycle pumps with reversed leathers are the most common means of obtaining a vacuum), also vacuum tubing;

(2) a suction flask, typically a 1-litre, thick-walled filtering flask with a side-tube (Erlenmeyer flask);

(3) a filter-holding unit and a ring stand;

(4) 60 by 15 mm glass or plastic Petri dishes for bacterial cultures;

(5) membrane filters (0.5 μm pore size) and nutrient absorbent pads 47–50 mm in diameter;

(6) curved forceps with rounded tips for manipulating filters and pads;

(7) a colony-counting apparatus with light source;

(8) dehydrated nutrient broth medium (available commercially).

Laboratory procedure

Media should be prepared and sterilized beforehand; sterilized, labelled glassware and standard solutions should be ready; sterile, buffered dilution water and data sheets should be prepared; water samples should be on hand.

(1) Open all the culture containers (Petri dishes); invert the covers of the containers and place them alongside the open dishes. Place 1 sterile absorbent pad in the bottom of each culture container. Use sterile forceps for manipulating absorbent pads.

(2) By means of a sterile pipette deliver enough prepared nutrient broth to saturate each absorbent pad. The amount of culture medium required for each absorbent pad is approximately 2 ml. Apply sufficient medium so that when the culture container is tilted a good-sized drop of medium freely drains out of the absorbent pad. Replace the covers of the containers.

(3) Place a sterile membrane filter, grid side up, on the basal part of the filter-holding unit centred over the porous part of the membrane-supporting plate. Membrane filters are easily damaged; for manipulations use sterile forceps and *always* grasp the filter disc outside the area of the filter through which the sample is to be passed. To keep the forceps sterile, *always* leave the working tips immersed in about 3 cm of ethyl or methyl alcohol; burn off the alcohol before using the forceps. Do not hold the forceps in the flame longer than is necessary to ignite the alcohol.

(4) Assemble the filtration unit, clamping the upper (funnel) portion to the basal part. Take care to avoid damaging the membrane filter in the filtration unit.

(5) Shake the sample bottle vigorously about 25 times, using an up-and-down motion.

(6) With the vacuum cut off, deliver the measured test sample of water into the funnel portion of the filtration unit. If the test sample is less than 10 ml first pour approximately (do not measure) 10 ml of sterile dilution water into the filtration assembly; if the sample is 10 ml or more this step is not necessary.

(7) Open the vacuum tap to hasten filtration of the sample through the membrane. After the sample has passed through the membrane filter cut off the vacuum.

(8) Rinse the funnel with 20–30 ml of sterile dilution water. Rinse again after all of the first rinsing water has passed through the filter.

(9) Disassemble the filtration assembly. Use sterile forceps to remove the membrane filter from the base of the filter holder. Carefully place the filter, grid side up, on the absorbent pad in the appropriate culture container. Inspect the filter for evidence of air bubbles between the absorbent pad and the filter. If necessary, reposition the filter on the absorbent pad. Since air bubbles interfere with the diffusion of culture medium from the absorbent pad through the membrane filter, limit the formation of bubbles as far as possible by placing enough culture medium on the absorbent pad and rolling the membrane filter into the proper position on the pad.

(10) After the completion of each filtration proceed to the next filtration in the series without resterilizing the filtration unit. The unit requires resterilization only after all filtrations in a consecutive series have been completed. If more than 15 minutes elapse between the filtration of successive samples resterilize the unit by immersing it in boiling water for 2 minutes and cool before further filtration.

(11) When the filtrations are completed invert the tightly closed culture containers and place them in an incubator at 35° ± 0.5°C or 44–45°C in an atmosphere saturated with water vapour for 18–24 hours. If the entire incubator does not have a saturated atmosphere place the cultures in a tightly closed container along with wet paper towels or other moist material.

(12) After incubation remove the cultures and count the colonies of coliform bacteria as follows: use a wide-field dissecting microscope or (less desirably) a simple lens. Position a lamp with a large illuminating surface close to the bacteria colonies and adjust it so that light is reflected directly from the surface of the colony into the microscope or lens. Colonies of coliform bacteria are red or pink and have a green-gold or metallic surface sheen. This sheen may cover the entire colony or may appear only in the centre of the colony. Noncoliform bacteria colonies range from colourless to pink or red, but do not have the characteristic surface sheen. Faecal coliform bacteria colonies are blue in colour.

(13) Record the coliform bacteria colony counts on a data sheet.

(14) If more than one sample volume was initially filtered, select one producing between 20 and 80 coliform bacteria colonies, divide the number of colonies by the number of mililitres of sample filtered, and multiply the result by 100. This will give the number of colonies per 100 ml of sample. Round the answer out to two significant figures. Example: assume that 34 coliform bacteria colonies were counted

on a membrane filter through which 25 ml of sample was filtered; then 34÷25×100=136. The number of coliform bacteria colonies per 100 ml (to two significant figures) is therefore 140. When incubating at 35°C report the count or number of bacteria of coliform group; for incubation at 44–45°C report the count or number of bacteria of faecal coliform group.

(15) When the culture has been incubated at 35°C report the number of colonies having a green-gold metallic surface sheen as the count of bacteria of the coliform group.

(16) When the culture has been incubated at 44–45°C report the number of colonies having a blue colour as the count of the faecal coliform bacteria.

Transport or storage of used membranes

A method has been devised in the United Kingdom whereby water samples are membrane-filtered on site or in a local laboratory with limited facilities (*34*). The membrane (with filtered bacteria) is then placed on a sterile filter-paper pad saturated with transport medium (see table below). The very dilute medium encourages the survival of filtered organisms without producing visible growth for up to 3 days in transit.

Membrane transport media[a]

Peptone	0.2 g	pH 7.5, sterilize by autoclaving at 121°C for 20 minutes
Sodium chloride	5.0 g	
Distilled water	1 000 ml	
or		
Peptone	0.2 g	
Sodium benzoate	4.0 g	
Distilled water	1 000 ml	

[a] Adapted from Panezai et al. (*34*).

By this means sterile plastic Petri dishes or aluminium tins containing used membranes can be sent by post or other local service to a central laboratory. On arrival, the membranes are removed and transferred to one of the selective media used for examination of water samples.

Annex 9

PARTICIPANTS IN THE WHO MEETING ON THE ESTABLISHMENT OF GUIDELINES FOR SURVEILLANCE OF DRINKING-WATER QUALITY

The following took part in the meeting held in Geneva from 18 to 24 February 1975 which led to the finalization of these guidelines.

Participants:[a]

Dr R. Allen, Director, Water Research Centre, Medmenham, Marlow, England (*Chairman*)

Mr J. A. Andu, General Manager, Western Nigeria Water Corporation, Ibadan, Nigeria (*Vice-Chairman*)

Professor R. O. Cordón, Professor of Sanitary Engineering, Regional School of Sanitary Engineering, Faculty of Engineering, San Carlos University, Guatemala City, Guatemala

Dr K. E. Hakim, Professor of Environmental Chemistry, High Institute of Public Health, Alexandria, Egypt

Dr G. P. Hanna, jr, Consultant, United States Agency for International Development, Washington, DC, USA

Mr R. R. L. Harcourt, Assistant Director (Environmental Health), Division of Public Health, Department of Health, New Zealand (*Rapporteur*)

Mr K. R. Sahu, Director, Treatment and Quality Control, Water Supply and Sewage Disposal Undertaking, Municipal Corporation, Delhi, India

Mr T. K. Tjiook, International Reference Centre for Community Water Supply, Voorburg, Netherlands

WHO Secretariat:

Dr F. E. McJunkin, Associate Professor, Department of Environmental Sciences and Engineering, University of North Carolina, Chapel Hill, NC, USA (*Consultant*)

Mr R. E. Novick, Sanitary Engineer, Community Water Supply and Sanitation, Division of Environmental Health, WHO, Geneva, Switzerland (*Secretary*)

Mr L. A. Orihuela, Chief, Community Water Supply and Sanitation, Division of Environmental Health, WHO, Geneva, Switzerland

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[a] Unable to attend: Dr S. Deak, Chief, Department of Water Hygiene, State Institute of Hygiene, Budapest, Hungary; Mr H. R. Shipman, Water Supply Adviser, Public Utilities Department, International Bank for Reconstruction and Development, Washington, DC, USA.

Annex 10

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