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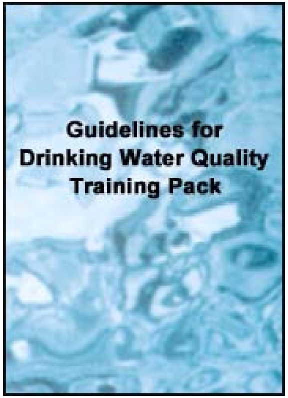

Guidelines for Drinking Water Quality - Training Pack (WHO)

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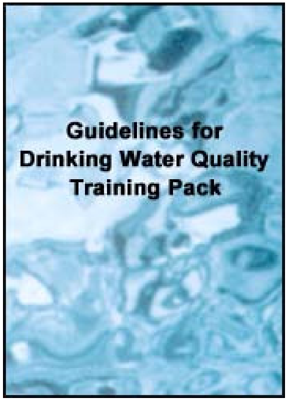

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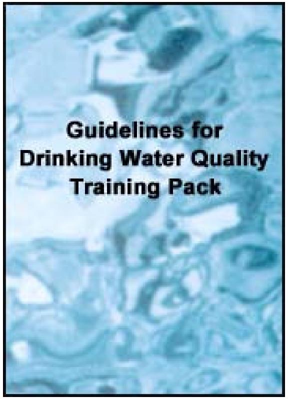


Guidelines for Drinking Water Quality - Training Pack (WHO)

Monitoring and Assessment of Microbiological Quality

Session Objectives

- **To describe the process of planning monitoring and surveillance activities and the need for progression through a number of stages**

starting with a pilot phase.

- **To describe the development of analytical ranges in water quality monitoring.**

- **To introduce the critical parameters concept and emphasise the need for monitoring to focus on health related parameters of water quality.**

- **To describe the design of sampling networks and frequencies of sampling in routine monitoring programmes.**

- **To discuss the linkage of monitoring to water supply improvement.**

Introduction

The routine monitoring and assessment of the microbiological quality of water is the key priority for both water suppliers and surveillance agencies. Microbiological quality is of principal concern because of the acute risk to health posed by viruses, bacteria and helminths in drinking-water. Therefore, monitoring and assessment of drinking-water is primarily a health-based activity which emphasises the protection of public health through ensuring that the water supplied is of a good quality.

Because monitoring is a health-based activity, other parameters of water supply should also be assessed: quantity, continuity, coverage and cost. All

these parameters will affect public health. The water supplier should aim to monitor all aspects of water supply within their area of responsibility and aim for a continuous water supply which is of sufficient quantity and quality at an affordable cost to be available to all the population connected to the supply. The surveillance body should monitor the entire population and identify unserved groups and actively promote universal access to adequate water supplies.

Strategies for monitoring of microbiological quality of safe water should also include hazard identification and risk assessment, processes commonly incorporated within sanitary inspection. It is important that these are systematic and quantifiable and can be used to facilitate decision making at local, regional and national levels on preventative and remedial actions. In addition, minimum treatment requirements and source protection should be emphasised as essential complementary activities to monitoring and assessment.

Planning monitoring and assessment

Monitoring water supply quality will only be effective and efficient if it is properly planned and implemented. In many countries where there has not been routine surveillance and surveillance programmes being developed there may be uncertainty as to what standards should be adopted, the number of water supplies that should be covered, how many samples should be taken, what should be analysed, frequency of inspection etc. These may

vary with time and it is important that the surveillance programme remains flexible and open to modification in response to evolving water quality priorities.

In many cases, WHO guideline values are adopted initially as the national standards for drinking-water quality. However, with time these may be superseded by national or regional standards depending on water quality priorities.

When designing a surveillance programme and planning its implementation, it is important that achievable aims and objectives are set. It is useful to clarify these terms: aims are general expression of targets, the 'end' result which is desired, are not generally time constrained. Objectives are indicators of the rate of success in achieving the aim and are specific goals set with definite time scales with indicators of achievement to provide a means of measuring success.

Extensive use of indicator bacteria will be required to monitor microbiological quality and the relative merits of these are discussed in the background paper on the microbiological aspects of water quality and in the *Guidelines* Volume 1. Thermotolerant (faecal) coliforms are the indicator most widely used for routine monitoring of water quality, although extensive use is also made of total coliforms. In addition to indicator monitoring, routine monitoring of turbidity and chlorine residual (in chlorinated supplies) is recommended in order to ensure that any deterioration of water

quality post treatment is rapidly identified.

The rest of this paper will discuss the development of strategies for water quality monitoring and assessment with specific reference to microbiological risks.

Aims and objectives

The aim of surveillance has been defined in *Guidelines for drinking-water quality. Volume III* (2nd edition) as follows: *"Surveillance is an investigative activity which is undertaken in order to identify and evaluate factors associated with drinking-water quality which could pose a risk to health. Surveillance contributes to the protection of public health by promoting the improvement of water supply with respect to quality, quantity, coverage, cost and continuity".* Guidelines Volume III also defines the aim of quality control in the water supply sector (which may be seen as an integral part of surveillance) as being: *"to ensure that water services meet national standards and institutional targets."*

In order to achieve these aims, a number of objectives may be identified, for example:

- **the formulation of working methodologies for information gathering, decision making and communication;**

- **the review of existing quality standards and modifications of these as appropriate;**

- **the identification of appropriate analytical techniques;**

- **the identification of appropriate equipment and facilities (including evaluation of the use of on-site equipment) required to conduct a surveillance programme;**

- **identification of analytical quality control procedures for laboratories and on-site techniques and the identification of national (and possibly regional) analytical reference centres;**

- **establishing staff requirements and assessing skills of current employees, identification of training needs for staff, recruitment needs for the sector;**

- **to establish a protocol for approval of water sources as fit for drinking;**

- **to establish whether there are any particular problems in terms of sources, treatment technology, designs, operation and maintenance regimes etc. which are leading to persistent contamination problems.**

The time in which it is expected to achieve these objectives must be outlined and indicators selected to measure progress, for instance definition of

appropriate chemical assay equipment or type of on-site equipment required.

Routine monitoring of water supplies

In many circumstances, there is a desire to attempt to apply all aspects of surveillance to all the water supplies immediately. Whilst this is a laudable ideal, it is rarely possible to achieve successfully and may lead to resources being over-stretched and the failure of surveillance to provide the expected improvements in water supply quality. This may in turn lead to disappointment and increasing apathy towards surveillance.

Surveillance should be introduced progressively and at each stage objectives set which are achievable and which positively promote the continued development of surveillance. The experience from earlier stages should be used to improve surveillance and lead to a progressively more efficient and comprehensive surveillance programme. Thus, in the initial stages of surveillance, activities may be restricted to sanitary inspections and critical parameter analysis on a restricted number of water supplies. As the programme develops, the number of water supplies covered will be increased, frequency of sampling and inspections increased and the analytical range increased.

Sanitary inspections can be carried out relatively cheaply and easily and can be implemented on all water supplies from the start of surveillance. Sanitary

inspection is as much a tool for the supplier or community as the surveillance agency for determining state of the water supply infrastructure and the identification of actual or potential faults and should be carried out on a regular basis by the supplier. The surveillance agency should conduct some independent inspections to verify the reliability of the supplier's information but this does not need to be as frequent.

In the long-term it is desirable that all water supplies should be included in a surveillance programme. However, it is important to be realistic in planning initial surveillance activities taking into account infrastructure, available trained personnel, the number of water supplies in the country and the ability to fund on-going surveillance activities.

Initial surveillance activities may be limited. However, it is important that short, medium and long tern achievable aims and objectives are included in the planning stage of surveillance. There should also be a set of clearly defined indicators that can be used to assess whether targets have been met. The establishment of credible indicators of a monitoring and evaluation programme at the start of the planning process is central to good planning of implementation. Time scales should be attached to each objective and aim and a proposed strategy for achieving these outlined.

Planned surveillance activities will only be possible if there are funds to pay for them and budgets for surveillance require careful preparation. In most cases, there are limited funds available and this inevitably will affect how

many supplies can be included, how often they can be visited and how many samples can be analysed. It is therefore imperative that the following are identified and the cost calculated: the number and location of water supplies to be included in each stage of surveillance; staff time; consumable requirements; equipment purchase and maintenance costs; fuel costs; the cost of reporting results to suppliers and communities; and the cost of follow-up activities. It is vital that all these elements are accurately budgeted for and cost-effectiveness achieved.

Pre-surveillance activities

Prior to the start of a surveillance programme, there are a number of activities which should be undertaken to ensure that the planners have access to all baseline data to design the surveillance programme. The pre-surveillance activities should provide the information concerning current status of water supply and surveillance in the country, and will include the following:

> ***Current surveillance activities:*** **scope; analytes; reliability; who is responsible; geographical spread.**
>
> ***Inventory of supplies:*** **type (borehole/spring/gallery/surface etc); treatment technologies; age; population served; existing quality data; source approval;**

Staff assessment: **numbers available; skills available; recruitment requirements; training requirements;**

Surveillance infrastructure: **available laboratories; laboratory equipment; on-site equipment; consumables; transport; geographical spread; computer availability; database availability.**

Once this information is available the programme can be designed and will include recommendations for improving on all the above and to test appropriate methods. It is usual to run a pilot project to evaluate the approach to be adopted and to identify any parts of the programme which require improvement.

Pilot project

There are essentially two approaches to the establishment of a pilot phase that can be adopted:

1. the use of a pilot project concentrated within one geographical area;

2. establishing surveillance on small scale national basis, with a small number of supplies included from each region.

Selected supplies may be restricted to those with large populations (for instance over 10,000 people or provincial capitals) or may include supplies

that serve all types of population centre.

The first of these approaches allows a more intensive allocation of resources and it may be easier to measure the effectiveness of the approach adopted. However, there is a risk that the area selected may not be representative or that successful approaches may not be replicable in other parts of the country. This may be due to different types of source or treatment used, different staffing structure or resource base. It may be difficult to develop and sustain the level of support available for a small regional, pilot-scale project on a national scale in the short term. Different regional water suppliers may have different priorities based on the principal threats to water quality in each region, the surveillance infrastructure available, the expertise available and the number of people served.

A national pilot project may be more expensive due to increased travel costs and may be difficult to manage. However, there are many advantages in this approach. It is much easier to establish a large-scale national surveillance programme if in the pilot phase a national approach was adopted. In this way, difference in priorities between regions will have been identified at an early stage and can be incorporated within the national plans. It will highlight any logistical, staffing or infrastructural problems that exist in a region and these can be planned against in the full programme. This approach is also likely to permit all types of water source and supply found in the country to be represented in the pilot phase, something that may be difficult to achieve in a single region.

Once the pilot project is complete and modifications made as required, the surveillance programme proper can start. The implementation of surveillance is likely to be staged over a number of years and short, medium and long term plans will have to be drafted.

Short-term plans

The short-term aim for a water surveillance programme should be to establish it as a perceived key priority of water supply and water resource management and to create an environment which actively promotes surveillance.

The short-term objectives of national surveillance programmes should be to achieve routine analysis of critical parameters covering a representative sample of all water supplies. There are no hard and fast rules determining this, but a figure of around 30 per cent of all water supplies has been adopted in some circumstances. If only a proportion of supplies is to be included initially, the supplies should be spread geographically, encompass examples of all (or at least the principal) source types and treatment technologies and should be concentrated on communities with larger populations. Given that protected groundwater sources tends to have less bacteriological contamination, it is common to include a greater proportion of surface supplies in the early stages of surveillance. Supplies where there are known problems with water quality should be included at this stage to try to establish the causes, rectify these and prevent their recurrence.

Where chlorinated water supplies are surveyed, from whatever source, turbidity and chlorine residual within the network should be tested regularly. As the equipment and consumables required are very cheap and testing is field based, it is feasible to test frequently and this may help reduce the number of microbiological samples required.

The number of microbiological samples taken and their frequency will vary depending on resources and population size, but as far as possible samples should be taken at least quarterly by the supplier and at least annually by the surveillance agency. The number of samples taken is largely dependent on population supplied, time available, analytical resources and type of distribution network. However, the more samples that are taken, the more representative the results. Below is a very crude guide for the minimum number of samples that should be taken:

Populations below 5,000	5 samples - 1 at treatment works outlet, 1 at storage tank, 3 in the distribution network;
5,000 - 10,000	7 samples - 1 at works outlet, 1 at storage tank and 5 in the network;
Over 10,000	7 samples + 1 extra sample per 5,000 population - 1 at works outlet, 1 at storage tank, rest in network.

If water supplies are from a point source, for instance a borehole or well, not connected to a pipe network, analysis need not be as regular. However,

there should be a minimum of two analyses per year - one wet season and one dry season - to take into account water level fluctuations and to assess whether quality varies seasonally.

Sanitary inspections should be carried out regularly by the supplier or the community on all water supplies and not merely those where analysis is being carried out. Sanitary inspections may be undertaken by staff such as systems operators or by trained community members.

Where there is a supply agency responsible for the provision of drinking-water, the results of the sanitary inspection and any recommendations for action should be noted and shared with the supply agency. An annual summary of inspection results should be passed to the surveillance agency which highlights any actions which have been recommended and the outcome of these.

Where the water supply is community managed, the results of the sanitary inspections should be used by them to plan improvements to their supply and an annual summary of the results should be passed to the surveillance agency. An annual independent sanitary inspection by the surveillance agency should also be carried out.

Training programmes should be initiated to ensure that staff are able to carry out surveillance activities and can pass on skills in sanitary inspection to communities. Staff from both the suppliers and the surveillance agency

are likely to require training, as are any community members involved in surveillance.

Medium-term plans

The medium-term aim of surveillance should be to review and consolidate the programme and expand it to cover a greater proportion of water supplies and to ensure that adequate standards are established.

One of the medium-term objectives of water surveillance should be to increase the coverage of the surveillance programme and to make modifications to the programme as appropriate. The proportion of supplies that have regular analysis of critical parameters should be increased, for example to 80 per cent. The additional water supplies included in the surveillance programme should be distributed to reflect population distribution and the number of groundwater supplies covered increased.

Chlorine residual and turbidity testing in the distribution network should continue to include all chlorinated water supplies and the frequency of testing increased. The number of samples taken from the distribution network for microbiological analysis should be increased and the supplier should aim to carry out microbiological analysis of samples at least quarterly and preferably monthly on large supplies. An independent analysis by the surveillance agency should be carried out at least annually or even more frequently on large supplies. The analytical range may also be extended to

include other parameters such as total coliforms or other faecal indicator bacteria.

Lines of communication should be established between supplier, consumer and surveillance agency and the population should be kept aware of water quality problems that arise and precautionary actions that they should adopt.

Quality standards may be revised or if in the initial phase employed the use of guideline figures for water quality, the second phase may well include adoption of legally binding water quality standards. Standards or guidelines for other substances of health importance, for instance nitrate, should be drafted and analysed for as frequently as feasible.

Sanitary inspections should continue to be carried out monthly by the supplier at *all* supplies and independent inspections carried out at least annually. Larger supplies and a significant number of other supplies should be inspected quarterly by the surveillance agency.

In addition, codes of practice and construction standards for plumbers and builders should also be established and supported within the legal framework. A system for licensing approved craftsmen should be established with them regularly assessed and if consistently blow acceptable standards, a mechanism established to revoke their licenses.

An on-going training programme for staff involved in surveillance should be established and cover analytical techniques, sanitary inspection techniques and community education. This should include ensuring that appropriate courses are offered and made accessible for staff with extensive experience but limited formal qualifications. In-service training in appropriate topics should be provided and taught through short-courses and 'on-the-job' training.

The national laboratory network should be increased and appropriate AQC procedures established to ensure analytical quality is maintained.

Long-term plans

The long-term expansion of the surveillance programme should be to include all water supplies in the country in the surveillance programme and to ensure that both the supplier and the surveillance agency undertake regular sampling and sanitary inspection. The long-term surveillance plan should include the assessment and revision if necessary of drinking water quality standards and these should be expanded to cover all substances of health and environmental importance.

Samples should be taken monthly for microbiological analysis and in larger supplies this should be expanded to weekly or daily. the surveillance agency should aim to undertake regular independent analysis. The number of samples taken from the distribution network for microbiological analysis

should be increased and should be representative of the entire network.

Sanitary inspections should be carried out by the suppliers on a monthly basis on larger supplies and at least quarterly on smaller supplies with independent inspections carried out quarterly or bi-annually. In chlorinated supplies, the supplier should sample for turbidity and chlorine residual at least weekly and in large supplies daily.

As in each phase of the surveillance programme, there must be clear lines of communication between supplier, consumer and surveillance agency. Legislation should be drafted which gives a framework of the steps to be taken by the supplier to inform the consumers and the surveillance agency when water quality is sub-standard. This should include time limits within which contamination must be reported and advice given about precautionary actions that should be taken by the consumer (for instance boiling). There should also be time limits imposed within which the surveillance agency should be informed of any failure to meet standards and proposed action.

Full analytical quality control and assurance procedures should be established and all laboratories where analyses are undertaken should be part of analytical quality control and analytical quality assurance programmes. A national reference centre should be established, possibly supported by a network of regional centres. There should also be clear guidelines for ensuring the analytical quality and reliability of results obtained from on-site equipment.

A human resource development strategy should be drafted which identifies sector training needs and how best training should be provided. This should include in-service training and establishment if appropriate of further and higher education courses which will produce appropriately qualified staff.

Conclusion

Monitoring and assessment of microbiological water quality is a key priority in the water sector which involves water suppliers, surveillance agencies and communities. It is a health-based activity and should include elements of hazard identification and risk assessment, through the use of systematic sanitary inspection, as a means of improving water supply quality.

Analysis of indicator bacteria should be supported by turbidity and chlorine residual testing and these elements, combined with sanitary inspection, should be used to define the sanitary status of the water supply.

Monitoring is best implemented through a series of stages to ensure that any problems in implementation are identified and rectified during the early stages of programme development. Initial pilot projects should test the methodology to be used and this should then be progressively implemented on a nation-wide basis.

References

Anon. ***Guidelines for Drinking Water Quality. Volume 3 (2nd Edition).*** **WHO, Geneva 1997**

Bartram, J. (1996) ***Optimising the Monitoring and Assessment of Rural Water Supplies.*** **PhD Thesis, University of Surrey.**

Bartram, J. and Balance, R. (1996) ***Water Quality Monitoring*****. Chapman and Hall, London**

Howard, G. ***Developing Drinking Water Quality Monitoring in Zimbabwe*****, ODA Project Reports 2-7, National Water Quality Analysis Laboratory**

Howard, G. (1997) ***Water Quality Monitoring: Key Issues and Approaches*****. Waterlines (in press)**

Lloyd, B. and Helmer, R. (1991) ***Surveillance of Drinking Water Quality in Rural Areas*****. Longmans' London**

Lloyd, B., Bartram, J., Rojas, R., Pardon, M., Wheeler, D. and Wedgwood, K. (1991) ***Surveillance and Improvement of Peruvian Drinking Water Supplies*****. ODA. Guildford.**

Presentation Plan

Section	Key points	OHP

Introduction	• routine monitoring and assessment of microbiological quality is the key priority for suppliers and surveillance agencies	**1,2,3**
	• microbiological contamination represents an acute risk to health and the health-based monitoring of water quality is crucial	
	• in order to safeguard health, other parameters of water supply quality should also be monitored including quantity, continuity, coverage and cost as well as water quality	
	• the water suppliers should monitor compliance with national standards and regulations within their area of service	
	• the surveillance agency should monitor water supply to all the population and identify unserved or under-served areas and promote improvements	
	• hazard identification and risk assessment should be included in sanitary inspection and should be systematic and quantifiable	
	• source protection and minimum treatment requirements are also key complementary activities	
Planning	• monitoring and assessment only effective when well	**4,5,6**

monitoring and assessment	planned and implemented	
	• monitoring of microbiological quality of water supplies must have key health related objectives which aim to maintain or improve water supply quality	
	• surveillance is the combination of sanitary inspection and water quality analysis and is essentially health-based water supply monitoring	
	• monitoring and surveillance activities should be well planned if there are to be effective	
	• it is important to develop monitoring programmes in stages to allow refinement of the programme with time	
	• this is particularly true where monitoring has not previously existed	
	• it is important to use pilot projects to test the approach proposed before any large scale implementation is undertaken	
	• the most sustainable approach to monitoring is one where short, medium and long-term plans are prepared from the outset	
	• initial priority should be given to those supplies which serve large populations	

	• all monitoring should be linked to improvements in water supply through identifying of appropriate preventative and remedial actions	
Analytical ranges	• this has led to the concept of the critical parameters by WHO	**7,8**
	• these are: thermotolerant coliforms, chlorine residual, turbidity and pH	
	• when developing monitoring initially concentrate on the critical parameters	
	• only expand the analytical range once full coverage of supplies with critical parameters has been achieved	
	• selection of new parameters should be these which either directly affect health or cause water supply rejection by consumers	
Design of networks	• the design of sampling networks should be well planned and done on the basis of a detailed knowledge of the water supply	**9,10,11**
	• sample sites must be representative of the: source; treatment plant; storage tank; household connection; and point of use.	
	• especially in early stages, it is important to take samples from points where it is known or suspected that problems	

	exist	
	• ensure samples are taken from main lines, remote branches and dead ends	
	• use supply zones in large supplies	
	• sample sites may be classified in a number of ways	
	• fixed samples are useful to pick up long term water quality variation and thus indicate whether a source or treatment plant is sustainable	
	• variable sites will pick up local and transient problems with water quality	
Sampling frequencies	• minimum sampling frequencies have been defined by WHO for piped and point water sources	**12,13**
	• where possible, sampling frequency should be increased	
	• it is often better to develop a few well functioning monitoring networks which actively contribute to water supply improvement to the basis for later development	
	• costs may be reduced in piped water supply by focusing monitoring on chlorine residual and turbidity	
	• where chlorine residual is <5TU and free chlorine residual>0.2mg/l it is very unlikely that faecal coliforms will be present and a test may not be necessary	
	• if this approach is adopted, some random samples for	

	faecal coliform analysis should still be taken.	
Linking monitoring to improvement	• water quality monitoring should be linked to improvement in water supply by identifying remedial and preventative actions	**14**
	• when planning interventions, it is likely to be necessary to prioritise supplies and actions on the basis of greatest risk	
	• thus systems which classify water quality and sanitary risk in broad quality groups are useful to identify supplies which present the greatest risk to health	
	• on larger scales (including national) water supplies can be ranked on the basis of greatest risk and these can be prioritised for action	

Why Monitor?

- **Protection of human health**
- **Compliance with standards and guidelines**
- **Situation analysis/impact assessment**
- **Environmental change and trends**
- **Rapid detection of faults and failure**
- **Prioritisation of remedial actions**
- **Adequate quality of service**

Five Key Elements for a Water Supply

- **Quantity: Enough water for everyone to drink, cook and bath, e.g. 30-100 litres/person/day**

- **Quality: The water will not cause disease in those drinking or using it**

- **Cost: The cost of sufficient water for basic needs is within everyone's reach**

- **Coverage: Water is available to everyone in the community**

- **Continuity: Water is available all day, every day**

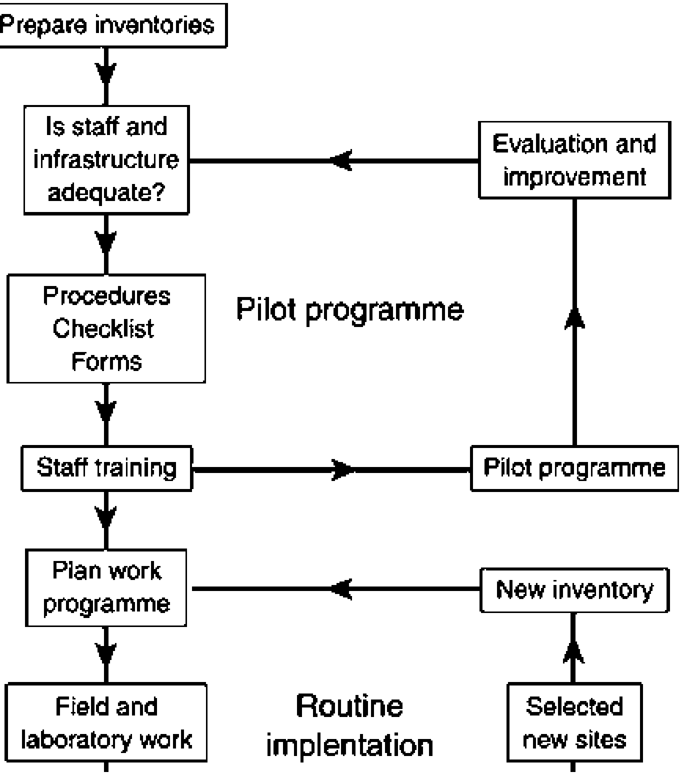
All five elements are vital if health is to be improved and maintained

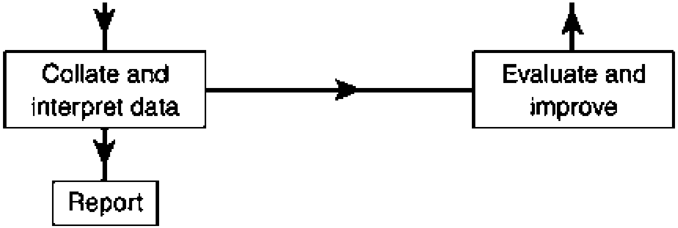
Ensuring Microbiological Quality

- **Source protection**
- **Minimum treatment requirements**
- **Sanitary inspection**
- **Water quality analysis**

Objectives of Water Quality Monitoring

- **Evaluate risks to the population**
- **Improve the situation**
- **Determine long-term trends**
- **Prioritise interventions**





Developing Water Quality Monitoring

Water Quality Surveillance

'...the keeping of a careful watch at all times, from the public health point of view, over the safety and acceptability of drinking-water supplies'

(WHO, 1985)

- **Source**
- **Treatment**
- **Distribution**

Coliform Analysis + Sanitary Inspection = Surveillance

Selection of Parameters

- **First Stage**
    - » **Critical parameters (WHO)**

» **Organoleptic parameters (taste, odours, colour)**
» **Known problem of public health concern**

- **Expansion of Analytical Range**

» **Should be the objective only once critical parameters are being used and improvements are being made**

- **Selection of New Parameters**

» **Those parameters which affect health**
» **Those parameters which lead to rejection of supply by consumers**

The expansion of the range of parameters must be progressive and allow priorities to be identified

Critical Parameters

Parameter	**Acceptable range**
Feacal coliforms	0/100 ml
Turbidity	< 5 NTU
Disinfectant residual	0.2-0.5 mg/l
pH	6.5-8.5

Samples must be analysed within 6 hours of taking the sample form a water supply. In areas where transport or roads are poor and this is not possible, portable water testing kits can be used

Design of Surveillance Networks

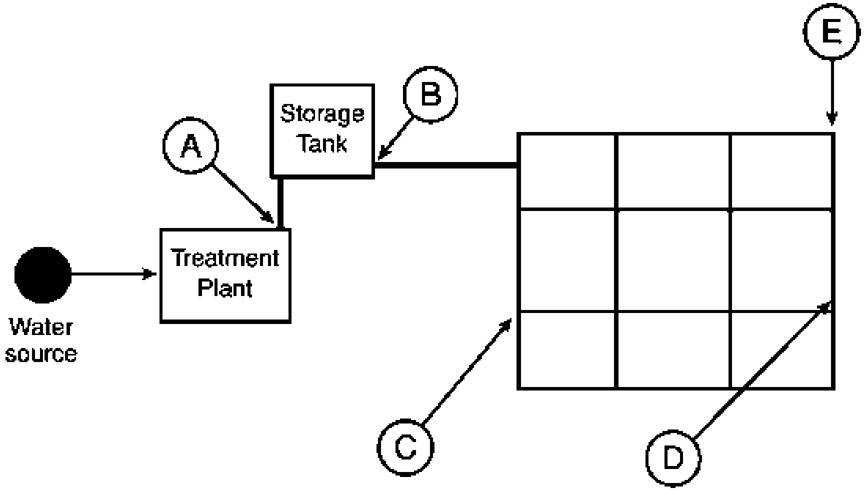
- **Site selection representative of:**

  » **Water source**
  » **Treatment plant**
  » **Storage tank**
  » **Household connection**
  » **Point of use**

- **Look at where problems are likely to occur:**

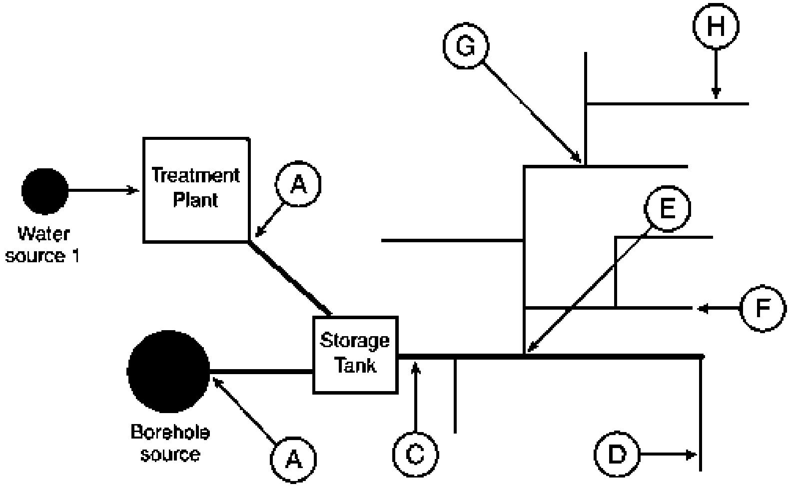
  » **Main lines**
  » **Remote branches**
  » **Dead ends**

- **Use 'zoning' for large systems with several sources.**



Sampling Network Design (Small supply)

Sample sites in a small water supply with ring main



Sampling Network Design (Large supply)

Sample sites on a large supply with an open network

Classification of Sample Sites

- **Fixed - Agreed in consultation with supply agency**

  » To help surveillance agency and water supply agency to compare results
  » Allows legal action to be used to ensure improvement

- **Fixed - No consultation with water supply agency**

» Used with other fixed sites to determine changes in water quality with time

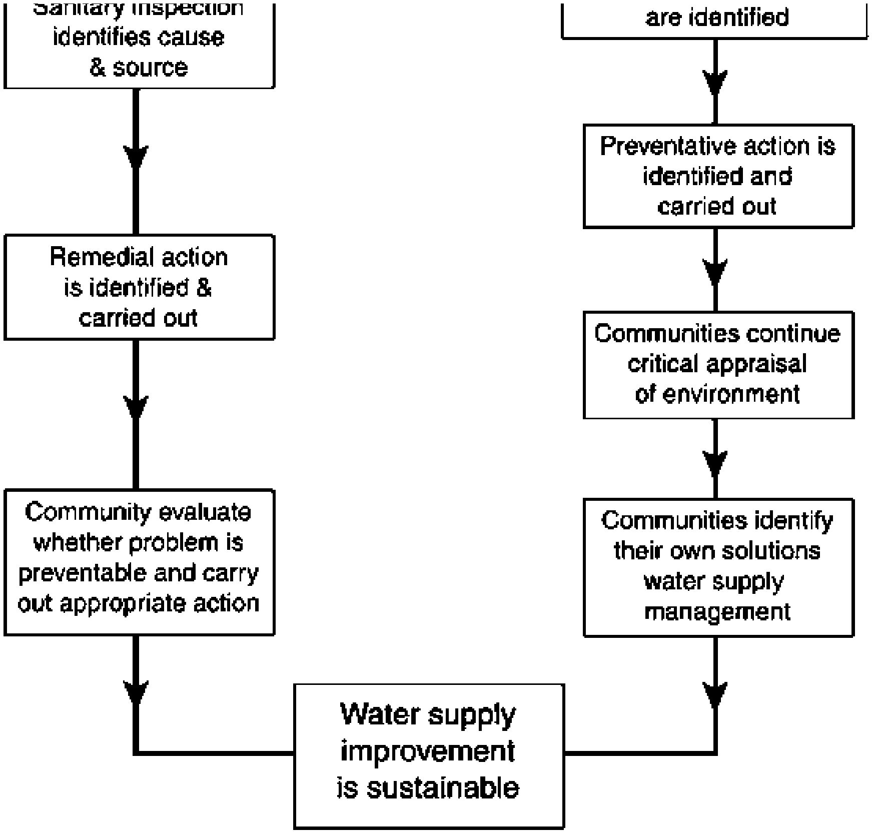
- **Variable - Samples taken at random by surveillance agency**

» Good for identification of local problems e.g. complaints, leaks

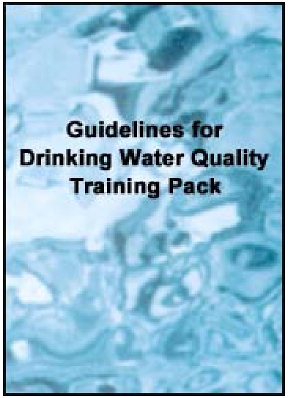
» Could include 'points of use' sampling

Minimum Sampling Frequency for Water Supply Systems

Population served	**Minimum frequency**
< 5000	1 visit each month
5000 -100 000	1 visit for every 5 000 population each month
> 100 000	20 visits each month plus 1 visit for every 10 000 population every month



Using monitoring to improve water supplies



Guidelines for Drinking Water Quality - Training Pack (WHO)

Monitoring and Assessment of Chemical Quality

Session Objectives

- **To highlight the relative priority for microbiological and chemical water quality monitoring and emphasis the need for a rational, health-based approach to monitoring of water quality.**

- **To outline the key characteristics of monitoring programmes which may be implemented for chemical water quality.**

- **To describe the analytical ranges commonly employed in chemical water quality monitoring, highlight key constraints in chemical**

analysis and stress the need for quality control.

- **To emphasis the value of risk assessment as a key supporting activity of chemical analysis and in planning monitoring programmes.**

Introduction

Chemical testing is generally not undertaken as frequently as microbiological analysis because, in general, the health risks posed by chemicals are chronic rather than acute and because changes in water chemistry tend to be longer-term unless a specific pollution event has occurred. It should be stressed that monitoring the microbiological quality of water is much more important than monitoring of chemical quality and chemical testing should generally be a lower priority.

However, where resources permit, routine testing of the chemical quality of water should be undertaken. Priority should be given to those substances which are known to be of importance to health and which are known to be present in significant concentrations in drinking-water. For instance, the monitoring of nitrate is recommended in many water supplies and in particular those which are located in rural areas, or where recharge occurs in an agricultural area. In these circumstances, regular monitoring is recommended to ensure that early warning of increases is noted or when nitrate releases are highly seasonal in nature.

An assessment of the chemical quality of water should be undertaken during source selection and this should relate to known activities within the catchment of the source and possible natural pollutants. This should be as comprehensive as possible and cover a wide range of pollutants.

In areas where toxic chemicals are released into the aquatic environment, routine monitoring should be undertaken and closely linked with an emergencies warning procedure which should function to alert water suppliers, surveillance agencies and health bodies of any accidental releases of substances into water sources.

Types of monitoring programme

As with any form of monitoring, it is important that clear objectives are set before the start of data collection activities and that sample sites and frequency of analysis are determined to meet the objectives and not vice versa. In the past, some water quality assessments have worked from the other way round and monitoring programmes have been designed to fit existing infrastructure. The problem with this approach is that it very often results in a failure to address the most pressing problems and also a failure to provide a full picture of the problem being monitored.

In general, monitoring of the chemical quality of water may be undertaken in two ways.

1. ***Routine monitoring of known problem substances:*** **this type of programme is designed to keep a continuous watch on substances which are known to have a health impact or compromise treatment efficiency and which are known or suspected to be in the water supply to be monitored. It is important that substances whose concentration is likely to change are monitored more regularly than those where concentrations are essentially stable. This is largely determined by the source of the contamination. Contaminants from essentially natural sources, such as fluoride, are unlikely to vary significantly over time and therefore do not require frequent analysis. Although there may be exceptions to this such as the raised arsenic levels in some groundwaters in West Bengal, India. Contaminants deriving from anthropogenic sources of pollution may require more frequent analysis, for instance heavy metals in water sources downstream of tannery waste discharges. Equally, where treatment is employed to remove or control specific substances (e.g. nitrate or phosphorous), these should be routinely monitored at the plant to ensure that treatment is effective.**

2. ***Periodic quality assessment:*** **this type of monitoring is either routine or non-routine assessment of water quality done on a relatively infrequent basis (annual or greater). Such assessments will certainly be done during the source selection procedure and may involve periodic evaluations of trends in water quality over time.**

Such assessments are likely to include a wider analytical range and be used to provide regular comprehensive assessments of water quality to assist in long-term water source and supply management and for long-term trend analysis.

Both approaches will concentrate on water quality in the source and as it leaves the treatment works or borehole, with a limited number of samples taken from within the distribution system, unless the materials used in the distribution system are suspected of providing a significant proportion of a harmful substance. In these circumstances it is usually more effective to monitor and control the quality of materials and chemicals used in water treatment during their production and prior to their use. However, where materials or chemicals have been used without quality control during manufacture, some monitoring of specific chemicals may be required by the public health agency. For instance, where lead pipes or lead-based solders are used, regular monitoring of lead may be recommended.

Selection of variables for monitoring and assessment

As mentioned above, during source selection, a comprehensive assessment should be made of water quality to ensure that any likely risks to health are identified and appropriate action taken with regard to source protection, treatment requirements and blending of water. Thus analysis of the major ions and nutrients should be done on all water supplies as well as any other substances deemed likely to be present on the basis of land-use within the

catchment of the source. However, whilst it is preferable to have a complete and comprehensive description of water quality before a water supply is commissioned, there are a number of constraints in trying to achieve this.

Many analyses are expensive to carry out, both in terms of the equipment required to perform the analysis and in terms of the consumable required. This means that if analysis is required for a particular analyte which uses sophisticated equipment, this may only be done occasionally when the laboratory has enough samples to make it economic to start up the equipment and run the analysis. It is never economic to start equipment such HPLC or a flame photometer to carry out a single analysis. Therefore appropriate storage facilities are required for the sample and appropriate preservatives must be available to prevent sample deterioration. This will further increase the costs of analysis.

Thus for some parameters, there may be a considerable time to wait before the results of analysis are known. However, the delay in opening the water supply, particularly in drought-prone areas, may be unacceptable. Therefore during source selection, parameters should be divided into essential and desirable. This should be done based on the risk to health, potential to cause consumer rejection, likelihood of causing operational problems, cost and ease of analysis, likelihood of presence in drinking-water.

The net result is likely to be a range of parameters which are analysed rapidly and perhaps on-site and before the source is commissioned (for

instance, nitrate, fluoride, iron etc.) and those which will be done, but possibly after the source has been commissioned.

There are a number of parameters which, when used in conjunction with a pollution source assessment, provide a good overall indication of chemical water quality and others whose impact on human health or the environment are great and should be included in initial testing. The presence at high levels of these parameters in the source water may indicate that other analyses are required. These include: nitrate, pH, Eh, fluoride, dissolved oxygen and chloride.

The presence of elevated levels of nitrate in water indicates pollution of the source and it is important that the type and source of the pollution is identified. Nitrate pollution may occur from agricultural source, sewage disposal and urban runoff. Agricultural sources may indicate that there will also be a problem with other agricultural pollutants such as pesticides. It is important that a survey is carried out to identify whether there is use of pesticides in the area and to find out application rates and time of application. Pesticide analysis is difficult and expensive, indeed there are a number of pesticides for which no analytical methods exists for detection in water, therefore routine analysis of pesticides will not be carried out at the start of a programme and is rarely fully developed. Nitrate contamination which can be linked to a sewage outfall may also indicate unacceptably high levels of microbiological contamination which should be addressed as a matter of priority.

For routine analysis, both the monitoring agency and the supplier should aim to concentrate on those chemical parameters which are of greatest health significance or provide a general description of water quality and for which analysis is inexpensive, quick and may be done on-site. There are variables such as pH and Eh (redox potential) which should, by preference, be done on-site as the sample may deteriorate during transport.

Risk assessment

As with microbiological monitoring, it is important that monitoring of chemical water quality is linked to a process of hazard identification and risk assessment. Thus when designing a monitoring programme, an inventory of likely sources of pollution and the likely vulnerability of a water source or distribution system to contamination should be made. This means that information will be required on the following:

- **geographical features, including topography, relief, lithology, climate, land-use, hydrology;**
- **other water uses from the source; and**
- **pollution sources, treatment of wastes and discharge consents in operation.**

Risk assessment should be a dynamic process which is conducted or

updated routinely by suppliers and surveillance bodies to ensure that no new risks are developing for which remedial or preventative action is required. Thus, for each new activity established within the catchment of the water source used for drinking purposes, a detailed description of likely pollutants that may be discharged, wastewater treatment arrangements, recycling and discharge consents must be obtained. These should be used to allow water suppliers and surveillance bodies to object to developments which will compromise public health through likely discharges and to establish monitoring programmes which are focused on health-based risk assessment.

Chemical testing of drinking-water supplies is often linked to source quality monitoring and thus it is very important that hydrological data are collected at the same time as quality data as this has a profound influence on water quality. Flows in rivers will determine the concentration of pollutants in the aquatic environment. For instance, in the UK at low flows, up to 95 per cent of the flow of many rivers which pass through urban areas is municipal effluent, whilst at high flows this percentage will be greatly decreased and effluent may only account for 30% of the flow.

The status of rivers with regard to groundwater is also important as this will influence water quality. Hydrogeological data are also important as water level, flow patterns and water movement rates will all affect water quality. For example, changes in water level may significantly alter water quality as pollutants removed from infiltrating water in the unsaturated zone by sorption may be eluted (de-sorbed) if the groundwater level later rises.

Quality control

It is important that data generated in chemical testing programmes in different regions are comparable and that time series of data are also comparable. Therefore: standard operating procedures are required for sampling, field testing and data reporting; AQC schemes should be carried out for all laboratories carrying out analysis; field equipment should be regularly checked and calibrated; staff should be adequately trained and supervised.

Provided the same analytical techniques are used over the time period to be studied and the above are implemented, data time series should be comparable. However, as analytical techniques are continually improving and changing, it is common to find that techniques for analysing particular variables change and that the results produced are not directly comparable to previous methods. When this happens, it is important that both the new and old technique are used to analyse samples for a hand-over period to allow a conversion graph to be prepared to allow comparison of the results of both methods.

Where there are a number of laboratories involved in water quality analysis, there should, preferably be some form of inter-laboratory comparison. This may take the form of a reference laboratory provided spiked samples to laboratories in which the concentrations of chemical constituents is not known by the participating laboratories. Alternatively, laboratories can

rotate quality assurance sample preparation. The purpose of such procedures is to improve the overall reliability of the data produced in water quality analysis.

Conclusion

Chemical monitoring is a lower priority than microbiological monitoring. As monitoring of chemical water quality is developed, a clear priority should be given to substances of known health impact and which are known or suspected to be in the water supply. Monitoring may be carried out routinely for some chemicals whose presence in water is likely to change over time, for which treatment is applied, or which have highly seasonal profiles. For most chemicals, and for all contaminants which have a natural source in the environment, monitoring may be done through periodic assessment of water quality.

Monitoring of chemical water quality should incorporate hazard identification and risk assessment as a key tool for managing risks. Thus, water suppliers and surveillance bodies should be aware of all potentially polluting activities within the catchment of a water source and use this information to help design monitoring programmes. Where activities involving the use or production of toxic chemicals, adequate emergency warning procedures must be established which will ensure that water suppliers and surveillance bodies are kept informed of any accidental spill into water sources.

References

Chapman, D. (ed) (1996) Water Quality Assessments. 2nd edition. Chapman and Hall.

Anon. (1993) WHO Guidelines for Drinking-water Quality, Volume 1. WHO, Geneva.

Howard, G and Simonds, A, (1995) Where there is no training - pollution risk assessment for field staff. Waterlines, Vol 14, No. 1. July 1995.

Presentation Plan

Section	Key points	OHP
Introduction	• chemicals evaluated during the preparation of the 2nd edition of the Guidelines	**1,2,3**
	• many chemicals, such as nitrate, lead and arsenic, can be toxic to humans and may come from natural and anthropogenic sources	
	• chemical testing not undertaken as often as microbiological testing because most health risks are chronic not acute	
	• changes in water chemistry also tend to be long-term unless specific pollution event occurs	
	• where possible do routine monitoring of chemicals of health	

	concern and known to be in drinking-water - e.g. nitrate	
	• comprehensive assessment of chemical water quality should be done during source selection	
	• early warning procedures essential and should link resource managers, water suppliers, surveillance agency and health bodies	
Types of monitoring programme	• need to have clear objectives before data collection starts and monitoring network should be designed to match objectives not vice versa	**4,5**
	• where objectives are set to match monitoring programmes may fail to meet most pressing needs	
	• two key approaches to chemical monitoring	
	1 routine monitoring of known problem substances	
	- designed for continuous surveillance of substances of health concern and which are in water supply	
	- only routinely monitor substances where concentration likely to change because of a pollution event or treatment failure	
	2 periodic quality assessment	
	- either routine or non-routine assessment of water quality on relatively infrequent basis	
	- assessment certainly done during source selection and subsequent occasional evaluations	

	- such assessments likely to have a broader analytical range than routine monitoring	
	• both types of monitoring tend to focus on sources and where water leaves pumping station or treatment plant unless distribution system suspected of leaching substances into the water	
	• where substances in water are derived from chemicals and materials used to treat and distribute water, it is often better to monitor and control manufacture than in drinking-water	
Variable selection	• preferable to have a complete description of quality of a water supply prior to commissioning, but may be problems in achieving this	**6**
	• many analytes expensive to analyse for and only economic for analysis of a limited number of samples, therefore may delay analysis	
	• this has implications for source commission as unacceptable in many circumstances to wait until results available for commissioning	
	• therefore need to identify a restricted range of analytes of health concern which can be used to indicate broader problems and which are relatively easy to analyse,e.g. nitrate and pH	
	• nitrate is of particular concern and in many circumstances is	

	routinely monitored and source identified as this may indicate other pollution	
	• for routine analysis concentrate on chemicals of known health concern and can be easily monitored	
	• some parameters should be done on-site to prevent sample deterioration	
Risk assessment	• monitoring chemical quality should also be linked to risk assessment and hazard identification	**7**
	• when assessing vulnerability make sure collect information on geographical/geological features that may increase vulnerability	
	• during risk assessment identify all likely sources of pollution	
	• risk assessment is dynamic and should be routinely undertaken	
	• both supplier and surveillance agency should be aware of new activities within the catchment to predict likely impacts on water supply	
	• need to collect hydrological/hydrogeological data as well as quality data	
Quality control	• need to be able to compare data from different regions and time series of data	
	• therefore quality control is essential and standard operating	

	procedures are required for sampling, analysis and reporting • all equipment, including field kits, require calibration and staff trained	
	• where techniques change over time, ensure that new techniques is calibrated against old technique to ensure comparability	
	• inter-laboratory comparison is important for improving and maintaining analytical quality	
Conclusions	• chemical monitoring is a lower priority than microbiological monitoring	
	• priority should be given to those parameters of known health concern	
	• routine monitoring should be done for parameters whose concentration is likely to vary, for which treatment is carried out or which have seasonal profiles	
	• hazard identification and risk assessment should also be carried out and an early warning system implemented	

Assessment of Health Risks of Chemicals in Drinking-Water

Number of chemicals considered

Inorganics	34
Organics	

Chlorinated alkanes	5
Chlorinated ethenes	5
Aromatic hyrdocarbons	6
Chlorinated benzenes	5
Miscellaneous organics	9
Pesticides	35
Disinfectants	6
Disinfectant by-products	23
TOTAL	**128**

Chemical Monitoring

- **Far lower priority than microbiological monitoring**
- **Comprehensive assessment of water quality recommended during source selection**
- **Must be linked to ongoing risk assessment**
- **Quality control and assurance are vital for compliance monitoring**

Toxic Chemicals in Water

Nitrate:

- **Causes acute health effect in infants**
- **May be pronounced seasonal variation**
- **Long-term levels increasing worldwide**
- **Nitrate often monitored routinely**

Lead:

- **Link to intellectual impairment**
- **Main source in water likely to be from pipes/solders**
- **Monitor lead in water *or* monitor use of lead pipes**

Arsenic:

- **Often natural source**

- **Release due to water table lowering (India) -arsenates are desorbed during recharge**

- **Release under urban areas related to waterlogging and raised pH from humic and fluvic acids**

Monitoring Chemical Contaminants

- **Chemicals are often difficult or expensive to remove**

- **Chemical pollutants from natural sources tend to vary slowly**

- **No universal indicator chemicals have been identified unlike indicator bacteria**

- **Therefore, monitoring at long intervals unless:**

  - a health problem is identified
  - treatment is applied to remove substance
  - a pollution event is recorded which may affect supply
  - upgrading/expansion of system is planned

Monitoring Strategies for PhysioChemical Monitoring

These vary according to parameter:

- **Critical parameters (turbidity, pH, chlorine residual) routine analysis**

- **Known/suspected problem with particular substance (nitrate, THM, etc.) - routine analysis**

Other parameters are analysed on an occasional basis:

- **If their presence is suspected at harmful levels (e.g. fluoride)**

- **During source selection and infrequently afterwards**

- **Once problem and scale is identified there is no value in regular monitoring as levels unlikely to change quickly.**

Physio-Chemical Monitoring

Parameters:

- **Temperature**
- **pH**
- **Conductivity**
- **Redoxpotential (Eh)**
- **Turbidity**
- **Total suspended solids**
- **Total dissolved solids**

Chemical compounds such as:

- **Chlorine residual**
- **Nitrate**
- **Fluoride**
- **Arsenic**
- **Aluminum**
- **Lead**
- **THMs**
- **Some pesticides, etc..**

Risk Assessment

- **Risk assessment should be ongoing**

- **Initial assessment during source selection should identify potential sources of pollution**

- **Pollution risks assessment should be carried out whenever a new activity starts**

- **Regular assessment will support analytical work**

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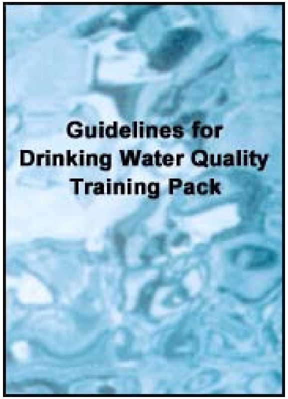

Guidelines for
Drinking Water Quality
Training Pack

Guidelines for Drinking-Water Quality Volume 3

Session Objectives

- **To describe the scope, purpose and content of Volume 3 of the Guidelines for Drinking-water Quality and the process of it's development.**

- **To describe the basic concepts incorporated within Volume 3 of the Guidelines and show how these should be addressed within the context of monitoring development.**

- **To describe the implementation of surveillance programmes in small communities and to emphasise the use the use of sanitary surveys, source protection and minimum treatment requirements in these areas.**

History and Development

The first edition of WHO *Guidelines for Drinking-water Quality* was published by WHO in 1984-1985 and was intended to supersede earlier European and international standards. Volume 1 contained guideline values for various constituents of drinking-water and Volume 2 the criteria monographs prepared for each substance or contaminant on which the guideline values were based. Volumes 1 and 2 of the Guidelines are therefore intended to be

supportive of risk assessment. In translating the information they contain into risk management, largely through standard-setting, Member States are encouraged to take social, economic and cultural factors into consideration.

Volume 3 was concerned with the monitoring and management of drinking-water in small communities, particularly those in rural areas - a problem of world-wide concern. In contrast to the first two volumes it therefore includes relatively extensive coverage of technical, managerial and organizational aspects.

A number of important principles were established in the first edition of Volume 3 of the Guidelines, published in 1985. These included:

- **the distinct and complementary roles of the water supplier and the surveillance agency;**

- **the unique nature of the problems associated with the monitoring of small community supplies;**

- **the central role of microbiological monitoring of supplies of this type, including the concept of critical parameter testing; and**

- **the importance of ensuring that surveillance leads to engineering improvements and other remedial measures.**

- **It also noted the importance of remedial measures and of**

community participation.

During the International Drinking-water Supply and Sanitation Decade 1981 - 1990 considerable experience was gained in the surveillance and improvement of small community supplies. The first edition of Volume 3 of the Guidelines for Drinking-water Quality provided a basis for a number of pilot projects and country programs in central and south America, Africa and various parts of Asia and the Pacific, several with the support of the Overseas Development Administration of the United Kingdom (ODA) and the United Nations Environment Program (UNEP). Regional and national training courses were conducted which were also supported by the Danish International Development Agency (DANIDA) and which allowed for the review and evaluation of the approaches and materials proposed in the Guidelines. In particular the experience gained through three demonstration projects supported in part by WHO in Indonesia, Peru and Zambia was reviewed and published in 1991.

Experience gained during the Decade highlighted the importance of additional concepts which were integrated into the second edition of Guidelines Volume 3. These included:

- **the need to consider water quality not in isolation but as one of a number of water supply service parameters which influence health;**

- **an understanding of the linkages between monitoring and**

improvement which then provided the structure of the document;

- **the fundamental importance of sanitary inspection and of its systematization;**

- **practical means to compare and present information on supply service quality to assist in decision-making; and**

- **the importance of addressing small community supplies of all types, including those to small peri-urban settlements.**

- **And the second edition therefore also included increased attention to human resource development and communication issues.**

The preparation of the second edition of the Guidelines Volume 3 was made possible through a grant provided by ODA to the Robens Institute, University of Surrey, UK and through the support of DANIDA to the second review meeting. The process began at a review meeting held in Harare, Zimbabwe 24 - 28 June 1991, when proposed changes were reviewed and a detailed outline agreed. A draft of the revised Volume 3 was reviewed at the Final Task Group Meeting on the Revision of the WHO *Guidelines for Drinking-water Quality* held in Geneva 21 - 25 September 1992. That meeting endorsed the general content of the draft, made specific recommendations for finalisation and recommended that a revised draft be reviewed at a technical meeting in Tirana in 1993 before publication. The

final version of Volume 3 reflected the experience of the three demonstration projects in Indonesia, Peru and Zambia and many other projects concerned with improving the quality of water services undertaken during the Decade.

Scope and Applicability of Volume 3

Volume 3 of the Guidelines specifically addresses the specific problems associated with the surveillance of 'community supplies'. The precise definition of a 'community water supply' will vary. Whilst a definition based upon population size or type of supply may be appropriate under many conditions, it is often administration and management that set aside community supplies. The involvement of ordinary, often untrained and sometimes unpaid community members in the administration and operation of water supply systems is often characteristic of small communities and this provides already distinction between community water supplies and those of larger towns and cities. However water supplies in peri-urban areas around larger towns and cities may be organizationally similar to those of rural communities and may also be classified as 'community water supplies'.

In addition to the voluntary and local nature of the operation and management of many community supplies, they present additional challenges to the surveillance function. These challenges include the fact that the quality control function which would normally be undertaken by the supply agency may be entirely absent - a local volunteer is unlikely to be able to undertake analytical quality control - and the role of the surveillance

agency may have to be modified accordingly.

Similarly, especially rural community supplies are often disperse and sometimes distant from the bases of operation of the surveillance agency. Organizing programs of regular visits to such communities presents a particular challenge and may be costly.

Finally, evidence clearly indicates that microbiological contamination is the principal health concern for community water supplies world-wide. Since microbiological contamination may vary widely and rapidly, approaches based upon sampling and analysis may be entirely inadequate in such supplies and great reliance must be placed upon preventive measures and sanitary inspection in order to ensure microbiological safety.

While conditions vary between countries and regions, as a result of differences in economic, geographical, cultural and social conditions, the strategies and procedures described in Volume 3 should be widely applicable.

Content and Structure

Volume 3 describes the methods employed in the surveillance of drinking-water supply and quality in light of the special problems of small-community supplies and outlines the strategies necessary to ensure that surveillance is effective. It is also concerned with the linkages between surveillance and

remedial action and with the form that remedial action should take.

The structure of Volume 3 reflects the principal stages in the development of surveillance and in shown in Figure 1 below.

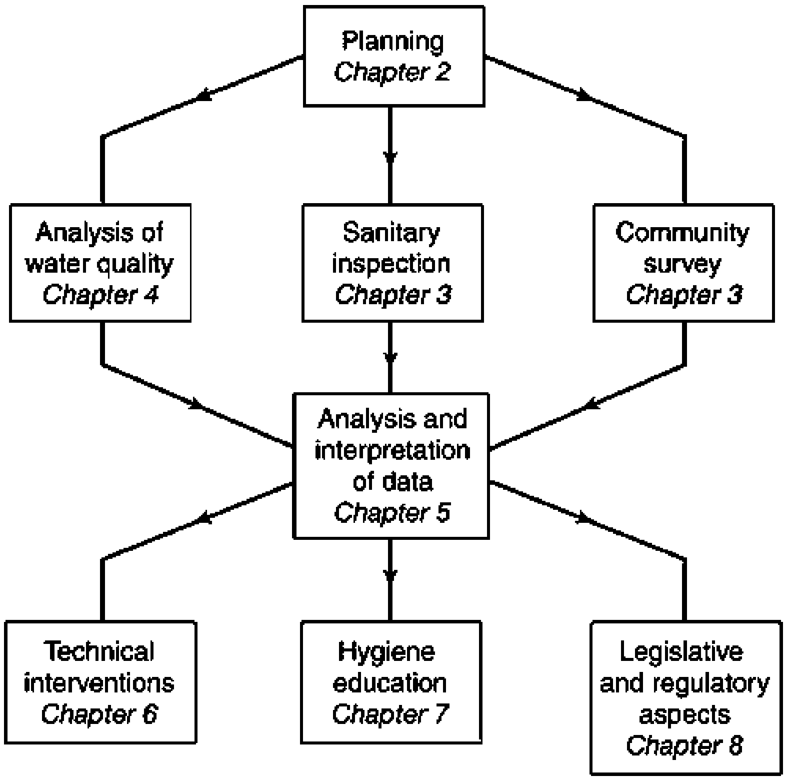


Figure 1: Structure of Volume 3 of the GDWQ

Chapter 2 covers planning and subsequent chapters deal with the procedures used in the collection of information - sanitary inspection and community surveys (Chapter 3), and the analysis of water quality (Chapter 4). Chapter 5 considers the analysis and interpretation of the information gathered and its use in improving water supply services. The final three chapters cover strategies for improvement - technical interventions (Chapter 6), hygiene education (Chapter 7) and legislation and regulation (Chapter 8).

Basic Concepts

The distinct and complementary roles of the water supplier and the surveillance agency

Organizational arrangements for the improvement of water supply services should take into account the vital and complementary roles of the agency responsible for surveillance and the water supplier.

In most countries the agency responsible for surveillance of drinking-water supply services is the Ministry of Health and its regional or departmental offices. In some countries there is an environmental protection agency; in others environmental health departments of local government may have some responsibility. Its responsibilities should encompass: the monitoring of compliance with supply service standards including quality, coverage,

quantity, continuity and cost by water suppliers; approving sources of drinking-water, and; surveying the provision of drinking-water to the population as a whole.

The surveillance agency should be given the necessary powers to administer and enforce laws, regulations and codes concerned with water quality. Surveillance is indispensable for the development of rational strategies for the improvement of the quality of water-supply services.

Water suppliers should be responsible at all times for the quality and safety of the water that they produce, and they achieve this through a combination of good operating practice and preventive maintenance, supported by quality control. Water quality control is the responsibility of the supplier and involves the establishment of safeguards in the production and distribution of drinking-water as well as routine testing of water quality to ensure compliance with national standards.

Quality control is distinguished from surveillance on the basis of institutional responsibilities and the frequency of monitoring activities conducted. The surveillance agency is responsible for an independent (external) and periodic audit of all aspects of safety, whereas the water supplier is responsible at all times for regular quality control, and for the monitoring and ensuring safe operations.

These two functions - surveillance and quality control are best performed by

separate and independent entities because of the conflict of interests that arises when they are combined.

The central role of microbiological monitoring

As noted above, evidence clearly indicates that microbiological contamination is the principal health concern in community water supplies world-wide. Furthermore, since microbiological contamination may vary widely and rapidly, approaches based upon sampling and analysis may be entirely inadequate in such supplies and great reliance must be placed upon preventive measures and sanitary inspection in order to ensure microbiological safety.

There are three principal components to the strategy which should be adopted and promoted. Firstly, systems should be intrinsically well-designed and capable of supplying safe water continuously. For groundwater sources this is generally achieved through source protection measures; whilst for surface water sources the selection of treatment processes and system capacity should take into account the quality and quality variations in the source water.

Secondly, regular inspections should be made to ensure that the system continues to operate safely. These sanitary inspections should take account of the whole of the supply system - from source to point of supply; and should systematically assess the condition of the system. Considerable

information is included in Volume 3 including examples of sanitary inspections forms for adaptation to local circumstances. Sanitary inspections may be performed by both the surveillance agency and by the community itself. Community inspections help to ensure a higher frequency of surveillance activity than the surveillance agency itself might be able to perform. When sanitary inspections are carried out, they must use standardized methodologies to allow the consolidation of data at regional and national levels in order to prioritize interventions and investment on the basis of greatest need.

Finally, not all sources of contamination are detected by sanitary inspection, however carefully performed, and it is therefore essential to undertake occasional sampling and analysis for the critical parameters of drinking-water quality.

The importance of ensuring that surveillance leads to improvement

For water supply surveillance to lead to improved drinking-water supply services it is vital that the mechanisms for promoting improvement are recognized and used. Information alone does not lead to improvement. It is the effective management and use of the information generated by surveillance that makes possible the rational improvement of water supplies - where 'rational' means that available resources are used for maximum public health benefit.

The ways in which surveillance may lead to improvements in water supply provision are dealt with in some detail in chapters 5 to 8 and are summarized in Table 1 below which is taken from Volume 3.

Table 1: Mechanisms for the improvement of water-supply services based on the results of water-supply surveillance

• **Establishing national priorities** When the commonest problems and shortcomings in water-supply systems have been identified, national strategies can be formulated for improvements and remedial measures; these might include changes in training (of managers, administrators, engineers, or field staff), rolling programmes for rehabilitation or improvement, or changes in funding strategies to target specific needs. • **Establishing regional priorities** Regional offices of water-supply agencies can decide which communities to work in and which remedial activities are priorities; public health criteria should be considered when priorities are set. • **Establishing hygiene education** Not all of the problems revealed by surveillance are technical in nature, and not all are solved by supply and construction agencies; surveillance also looks at problems

involving private supplies, water collection and transport, and household treatment and storage. The solutions to many of these problems are likely to require educational and promotional activities coordinated by the health agency.

- **Enforcement of standards**

Many countries have laws and standards related to public water supply. The information generated by surveillance can be used to assess compliance with standards by supply agencies. Corrective action can be taken where necessary, but its feasibility must be considered, and enforcement of standards should be linked to strategies for progressive improvement.

- **Ensuring community operation and maintenance**

Support should be provided by a designated authority to enable community members to be trained so that they are able to assume responsibility for the operation and maintenance of their water supplies.

Parameters of water supply service quality

While the safe quality of water supplied to communities is an important consideration in the protection of human health and well-being, it is not the only factor that affects the health of consumers. Access to water is of paramount concern and other factors such as the population served, the reliability of the supply and the cost to the consumer must therefore be

taken into account. At the United Nations Conference at Mar del Plata in 1977 which launched the International Drinking-water Supply and Sanitation Decade, this philosophy was unambiguously and the Conference Declaration included the statement that: ***'all peoples, whatever their stage of development and social and economic condition have the right to have access to drinking-water in quantities and of a quality equal to their basic needs'*****.**

Access to water may be restricted in several ways, e.g. by prohibitive charges, daily or seasonal fluctuations, breakdown, or lack of supplies to remote areas. Seasonal, geographic and hydrological factors may conspire to deprive households, communities or regions of a continuous, reliable supply of safe drinking-water. Such problems are not confined to poorer countries: they are also experienced in industrialized countries where the management of demand has failed or population growth has outpaced the rate of development of water resources for example.

If the performance of a community water supply is to be properly evaluated a number of factors must be considered. Quantitative service indicators for this purpose may include:

quality	the proportion of samples or supplies that comply with guideline values for drinking-water quality and minimum criteria for treatment and source protection
coverage	the percentage of the population that has a recognizable (usually public)

	water supply system
quantity	the average volume of water used by consumers for domestic purposes (expressed as liters per capita per day)
continuity	the percentage of the time during which water is available (daily weekly or seasonally)
cost	the tariff paid by domestic consumers

Need to address the population as a whole/all community supplies

It is those persons with inadequate or no water supply who are at greatest public health risk. It is technically possible, effective from a public health viewpoint and ethically desirable to identify such populations and to target them for improvements. Thus whilst the supply agency should be responsible for the quality of the service they provide, the surveillance agency should seek to assess the water supply to the population as a whole - including identifying the extent of supply within 'supplied' communities, identifying communities with no supply and determining the means of provision employed by the 'disperse' population.

Implementation

Surveillance is an investigative activity undertaken to identify and evaluate factors associated with drinking-water which could pose a risk to health. Surveillance contributes to the protection of public health by promoting

improvement of the quality, quantity, coverage, cost and continuity of water supplies. It is also both preventive - detecting risks so that action may be taken before public health problems occur - and remedial identifying the sources of outbreaks of waterborne disease so that corrective action may be taken promptly.

Surveillance requires a systematic program of surveys that combine sampling and analysis, sanitary inspection and institutional and community aspects.

Conclude presentation with a summary:

This presentation has covered:

- **the history of Volume 3, its special character and purpose in addressing a specific problem of world-wide concern.**
- **the key principles underlying the volume and concerning surveillance of community supplies.**
- **the structure and content of volume and how it relates to the implementation of a surveillance program.**

Presentation Plan

Section	Key points	OHP

History and Development	• first edition of the GDWQ published 1984-5 in 3 volumes	**1,2,3**
	• volume 1: guidelines; volume 2: criteria and supporting information; volume 3: community water supplies	
	• volumes 1&2 provide risk assessment, whilst volume 3 emphasises implementation in small community water supplies and covers other aspects	
	• 1st edition established key principles (see OHP2)	
	• in IWSSD (1980s) considerable experience in small community water supplies and pilot projects used to test and refine volume 3	
	• this led to additional concepts included in volume 3	
	• volume 3 reviewed at 2 meetings and finally Tirana in 1993	
Scope and applicability of Volume 3	• volume 3 specifically addresses community-based water supplies	**4**
	• community supplies defined on the basis of management/administration rather than population size or type of supply	
	• community supply may cover both peri-urban and	

	rural water supplies operated and managed by non-professional community members	
	• community water supplies present unique monitoring problems, there is often no quality control function and thus modified surveillance role	
	• rural communities often dispersed and many in number making surveillance costly	
	• need to emphasise preventive actions and non-analytical approaches to surveillance to ensure microbiological quality	
Content and Structure	• volume 3 outlines methods for surveillance in community water supplies and in particular the linkage of surveillance to improvement of water supplies	**5**
	• the structure of the document reflects the stages of surveillance development for community supplies	
Basic Concepts	*Distinct and complementary roles of supplier & surveillance agency*	**6,7**
	• institutional structure of the water sector must recognise the vital and complementary roles of suppliers and surveillance agencies	
	• surveillance usually done by MoH, but sometime by	

	MoE or local government and should encompass quality, quantity, continuity, coverage and cost	
	• surveillance agency should enforce water laws and use monitoring data to improve water supplies	
	• water suppliers responsible for quality control of water they supply	
	• surveillance is independent audit of water supply	
	• should separate institutions undertaking quality control and surveillance to prevent conflict of interest	
	Central role of microbiological monitoring	
	• microbiological contamination is principal health concern in community water supplies	
	• microbiological contamination may vary widely and rapidly, therefore analytical approaches alone are not adequate	
	• sanitary inspection and preventive measures are essential	**8,9,10,11**
	• approaches to community water supply should ensure that:	
	a) systems are well-designed to provide safe water continuously (source protection & minimum treatment)	
	b) regular sanitary inspection carried out on all system	

	to ensure risks rapidly identified and eliminated c) occasional water analysis carried out of critical parameters	
	Importance of linking surveillance to improvement	
	• surveillance must link to improvement and mechanisms to achieve this must be identified	
	• information alone is not sufficient, but the rational use of information for improvement of water supplies (prioritisation, identification of faults etc.)	
	Parameters of water supply	
	• must address all aspects of water supply	
	• access must be seen as the key priority	
	• also take reliability, coverage and cost into account	
	• there can be many reasons why access to water supplies may be restricted	
	• when evaluating performance of community water supplies, can use five quantitative indicators: quality, quantity, continuity, coverage & cost	
	Need to address community as a whole	
	• those parts of population with inadequate or no water supply at greatest risk	
	• should target these groups for investment	

	• supply agency responsible for ensuring adequacy of supply to the 'supplied' population	
	• surveillance agency should assess whole population, identify those not supplied and determine mechanisms to rectify this	
Implementation	• surveillance is an investigative public health-based activity	
	• surveillance protects health through promoting improvement in water supply	
	• it is both preventive and remedial	
	• surveillance is systematic and includes analysis, inspection, institutional and community aspects	
Conclusions	• have covered summary of volume 3	
	• shown the principles underlying volume 3	
	• provided structure and content of volume 3 & its implementation	

WHO Guidelines for Drinking-Water Quality

Volume 1 Recommendations

Volume 2 Health Criteria and other Supporting Information (IPCS)

Volume 3 Surveillance and Control of Community Supplies

Volume 3 Surveillance and Control of Community Supplies

Principles Underlying Volume 3

- **Suppliers and surveillance agency have distinct and complementary roles**

- **Small & community water supplies have unique require a different approach to monitoring**

- **Critical parameter testing is of paramount importance**

- **Surveillance must be linked to improvements in water supply**

- **Many small supplies are community managed and therefore community participation is essential**

Lessons learnt during the IDWSSD

- **Key parameters: quantity; quality; continuity; coverage; and cost**

- **Linkages between monitoring and improvements must be clearly understood**

- **Sanitary inspections are essential and should be systematic**

- **Water supply monitoring data must be comparable to be of use**

- **Community supplies, including those inperi-urban areas, must be addressed**

- **Human resource development and communication of monitoring information are vital**

Scope and Applicability of Volume 3

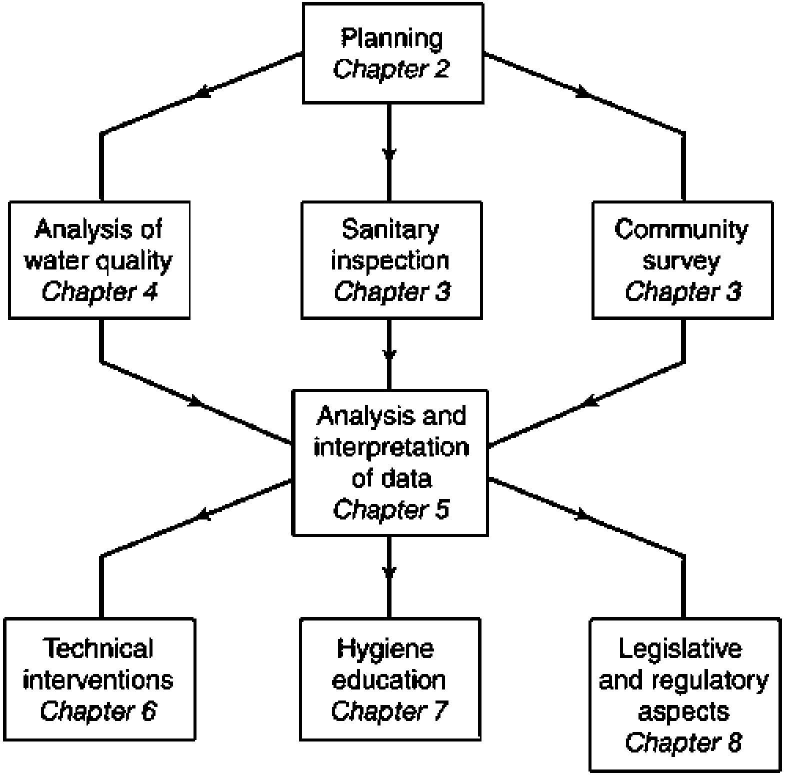
- **Specifically addresses community-based water supplies**

- **Community supplies may cover both peri-urban and rural water supplies operated and managed by nonprofessional community workers**

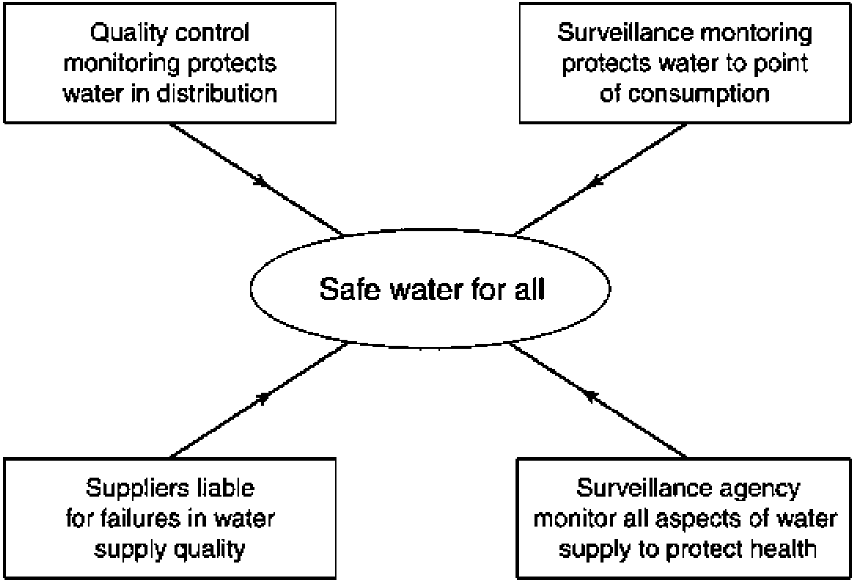
- **Community water supplies present unique monitoring problems often with no quality control**

- **Rural communities often numerous and dispersed thus making surveillance costly**

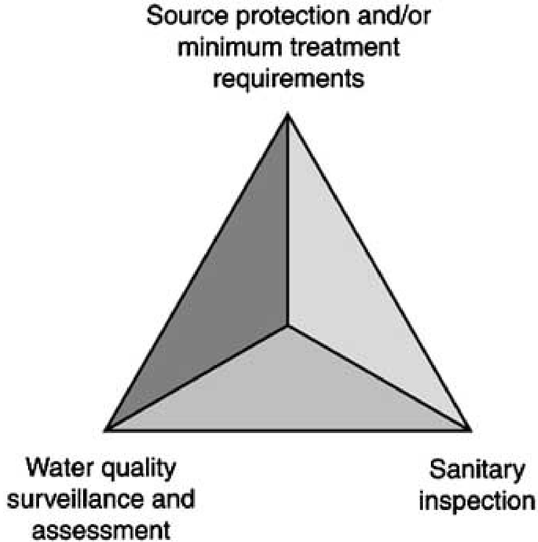
- **Need to emphasise preventative actions and nonanalytical approaches to surveillance to ensure microbiological quality**



Structure of Volume 3 of the GDWQ



Distinct and complimentary roles of suppliers and surveillance agencies



Strategy for water supply quality protection and improvement

Critical Parameters

Parameter	Recommended Level
Faecalcoliforms	0 per 100 ml
Turbidity	<5 NTU
Disinfectant residual	0.2 - 0.5 mg/l
pH	6.5 - 8.5

Note: Samples must be analysed within six hours of taking the sample from a water supply. In areas where transport or roads are poor and this is not possible, portable water testing kits can be used.

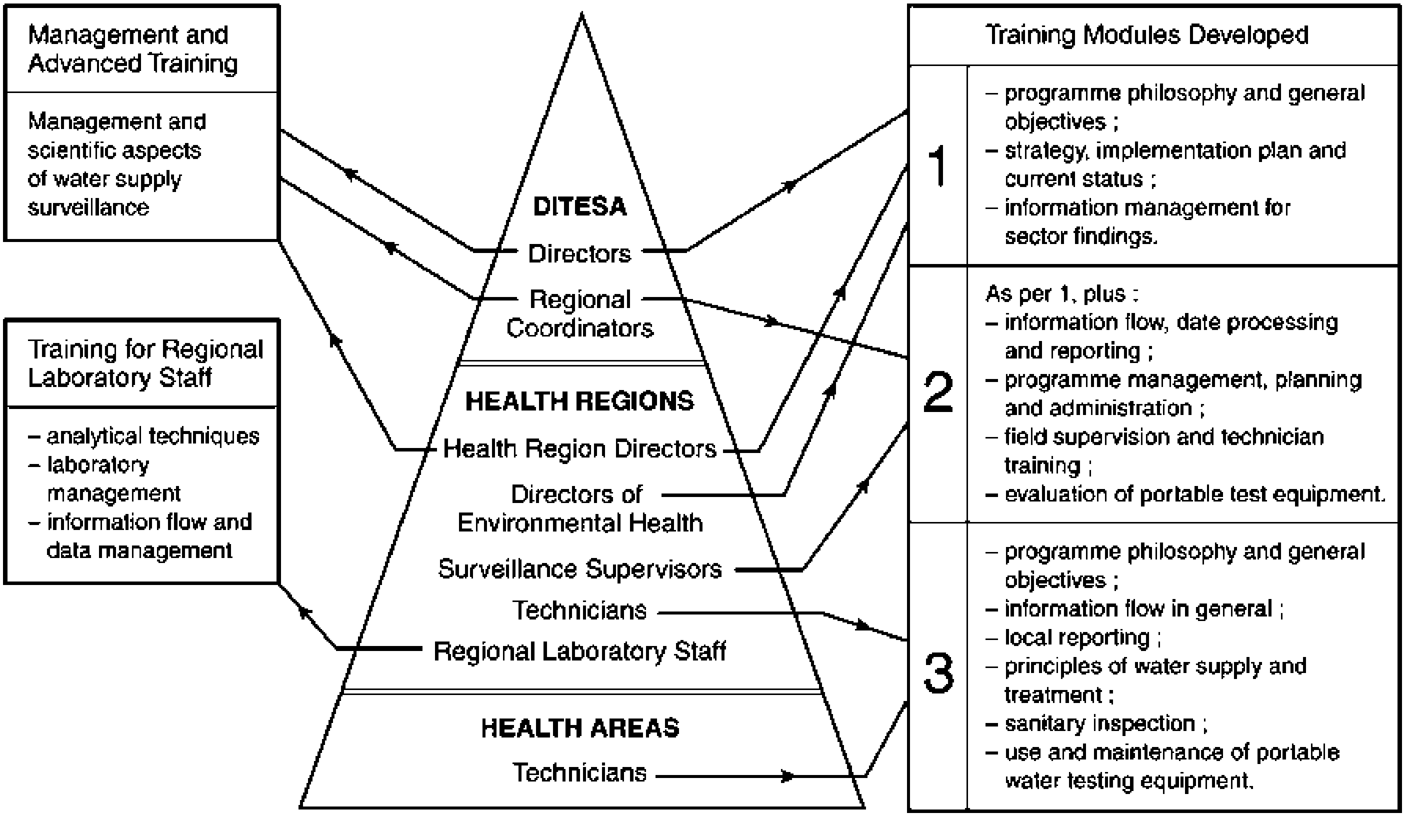
Use of monitoring data to improve water supply

- **Establishing national priorities**
- **Establishing regional priorities**
- **Establishing hygiene education**
- **Enforcement of standards**
- **Ensuring community operation and maintenance**
- **Human resource development and communication of monitoring information are vital**

Five Key Parameters of Water Supply Service

- **Quality**
- **Coverage**
- **Quantity**

- **Continuity**
- **Cost**



Human Resources Development for Water Supply Surveillance in Peru

Source: Lloyd et al., 1991

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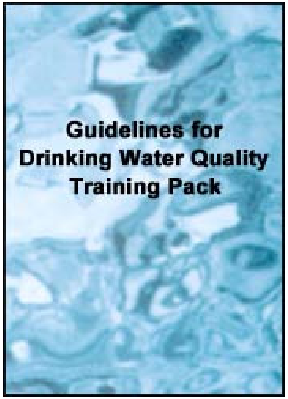


Guidelines for Drinking Water Quality - Training Pack (WHO)

Source Protection

Session Objectives

- **To describe the need for the protection of water sources and resources.**

- **To define the terms 'source protection' and 'resource protection'.**

- **To discuss the influences on quality of water in the environment and the importance of human activities on water quality deterioration.**

- **To describe some of the preventative measures that are applicable to groundwaters.**

- **To describe some of the preventative measures that are applicable to surface waters.**

Introduction

The prevention of water contamination is always preferable to attempting to remove contamination once it has entered the aquatic environment. Whilst it is likely that some contamination events will always occur, a large proportion of drinking-water quality problems can be prevented through: adequate source protection and good water resource management; good design, operation and management of water supplies; and regular and thorough surveillance activities.

The initial selection of a source for drinking-water should ensure that the best source is selected. This can be done by carrying out a thorough analysis of source water quality and making a comprehensive assessment of the vulnerability of the source to contamination. This should obviously be done

before any investment is made in construction.

The quality of the proposed source water should be tested under "worst case" conditions (those periods when contamination is most likely to occur such as the start of a wet period or when groundwater levels are raised) whenever possible. A sanitary inspection and pollution vulnerability assessment of the source should also be undertaken under "worst case" conditions.

If the source is contaminated, this may not preclude it's use as a source of drinking-water, as it may still be the best quality source available and/or the best source on other grounds such as cost, availability and quantity. Initial analysis should provide information on the nature of contaminants present and therefore an indication of what treatment processes will be required to remove them prior to distribution. A sanitary inspection should indicate the risk to the source from sources of microbiological contamination in the immediate surroundings of the source and suggest measures that may be taken to protect the source from continued contamination. A pollution vulnerability assessment will provide information on the risk to the source of contamination from a wider perspective and identify potential risk from chemical contamination.

Water source protection

Water source protection is a mixture of localised measures designed to

protect individual sources and wider ranging measures designed to protect the larger water resource body. The latter can be on a provincial, national or regional (international) basis. For surface waters, the most appropriate level to protect water sources is though basin management. Depending on the size of the catchment area and water body, this may mean working on a scale ranging from district or provincial level up to international treaties involving several riparian countries (for instance the Nile and Zambezi basins).

As surface water sources and resources are far more open to contamination and potential catchment areas of contamination are generally far larger than for groundwater. Thus, any measures taken to protect surface water resources will generally encompass a far wider geographical region than measures designed to protect groundwater resources.

It is important that both localised and wider measures are undertaken to protect sources used for drinking-water supplies. Local measures are required to ensure that the actual water source is not at risk from contamination in its immediate environment. An example of this is well-head completion measures on the top of boreholes which ensure that the top of the borehole is sealed against the entry of contaminated surface water. Large-scale measures are required to ensure that valuable water sources are not lost because of contamination of the water body some distance away from the drinking-water source. An example of this is the definition of land-use zones around important aquifers to limit potential contamination.

Groundwater protection

Groundwater is an important source of drinking-water. In its natural state, groundwater is generally of high microbiological quality with little or no contamination, although some groundwaters do have high levels of harmful chemicals such as fluoride and arsenic. The relative purity of groundwater in its natural state is largely a result of infiltration through the soil and unsaturated layers of rock. During infiltration attenuative processes such as sorption, mechanical filtration and ion exchange operate which remove bacteria and some chemicals, particularly metals, from the water. However, some chemical compounds, such as nitrate, are not easily attenuated and once in the sub-surface aquatic environment are highly persistent and mobile. It is thus important that such chemicals are prevented from entering aquatic systems.

Once an aquifer is contaminated, as the movement of water through sub-surface systems relative to their volume is slow and residence times are lengthy, the natural processes of removal by dilution and discharge to surface waters may be extremely long (decades, centuries or millennium). Thus prevention of contamination of groundwaters by persistent mobile contaminants is an essential element in the protection of groundwater resources. A further complication is that many attenuative processes in the saturated zone are reversible and whilst initially contaminants may be removed from solution through, for instance sorption, at a later date they may be desorped and re-enter the water. This is a common problem in

industrial cities in western Europe, where initial development led to a decrease in the water and subsequent attenuation of contaminants in the unsaturated zone. Subsequent development has occurred elsewhere using different water sources leading to a recovery of groundwater levels and desorption of contaminants and groundwater pollution. For instance there has been a noticeable increase in the levels of heavy metals in recovering groundwaters beneath London.

Different types of aquifers are vulnerable to contamination to differing degrees. Generally where aquifers are overlain by a substantial unsaturated zone and have high primary porosity and reasonable permeability, they tend to be less vulnerable to pollution. Aquifers where water is primarily held in secondary porosity (fissures and joints) tend to be more vulnerable to contamination as the water has less opportunity to undergo attenuative processes which remove contaminants.

This has led the concept of "Groundwater Protection Zones" where acceptable land uses are defined in order to protect the underlying groundwater. These zones were originally developed in Western Europe, particularly Germany and the Netherlands, to prevent contamination of groundwater supplies by pathogens and thus reduce the incidence of water borne diarrhoeal diseases. The delineation of groundwater protection zones is done by establishing the length of time a substance or organism takes to become non-harmful and the distance this represents under groundwater flow conditions.

Microbiological groundwater protection zone are established on the basis that the vast majority of pathogenic bacteria die off within 50 days of being in groundwater under normal conditions. Thus by establishing the distance travelled by groundwater in 50 days for a particular area, a zone can be defined from the abstraction point.

The definition of zones for chemical protection has also been attempted but this has been far less successful than the delineation of microbiological zones. This is because, unlike microbiological survival rates, it has proved extremely difficult to establish or even estimate the half-life of many chemicals in groundwater. Not only is there a vast number of chemical compounds which may be found in water, but groundwater and aquifers (particularly hard rock aquifers) frequently have a complicated chemistry themselves which may interact with pollutants and extend or reduce half-life. A 400-day isochron has been suggested in some quarters as being sufficient, but in reality far more work is needed in this area and chemical persistence will vary with different chemicals and aquifers.

Groundwater Protection Zones may take many shapes. They are very rarely simple circles drawn with an abstraction point as the centre. There are many factors which will influence the shape of the zone: the nature of the aquifer (which are very rarely isotropic); the number of rivers in the zone; the condition of rivers (whether influent, effluent, perched or changing); and the number and location of other abstraction points within the zone.

Surface waters which overlie an aquifer will extend the zone along its course upstream as contaminants are likely to move more quickly in surface water. It is important to establish what relationship the river bears to the aquifer, as obviously where a river is supplied by the aquifer the protection zone need not be as extended as when the river recharges the aquifer. However, it is always likely that a river will be influent to an aquifer at some point along its course. Even under effluent conditions there will be river-groundwater interaction and the extension of a zone some way along river which is recharged by the aquifer is always to be recommended. The more rivers associated with the aquifer, the greater the distortion and extension of the zone.

Within the protection zone, land use may be restricted to non-polluting activities and ensure that any discharges within the zone meet stringent quality standards. This may be problematic where there is intensive agriculture with widespread use of inorganic fertilisers and pesticides. In these cases, permitted application loads may be introduced and groundwater quality monitored. In these circumstances is often found that producers can reduce applications whilst maintaining yields, although it is possible that some form of compensation for loss of production may have to be provided. Where intensive animal production is practised, adequate isolation and treatment of slurries should be carried out by the farmer and leakage to groundwater minimised.

Surface Water Protection

Surface waters are particularly vulnerable to contamination from agricultural, industrial and municipal sources. Surface water bodies receive wastewater from industrial and municipal sources, agrochemicals may leach into them, air-borne pollutants may dissolve in surface water and they receive overland run-off which washes surface debris. As a result, all surface waters require treatment before they are supplied for drinking-water, whether the source is a river, lake or reservoir.

There are a number of interventions which will help to protect the quality of surface waters, principal amongst these are: land-use control within the catchment; and proper siting of intake structures away from potential sources of pollution and preferably upstream of them; treatment of effluent and discharges leaving industrial plants and municipal sewage treatment works, and; the establishment and enforcement of effluent quality standards.

Where surface water is used as a source of drinking-water, it is appropriate to ensure that land use within the catchment is controlled and preferably limited to activities which are relatively non-polluting. This can be problematic as some activities may already be established which do cause pollution and in these cases, adequate standards of effluent quality should be established and enforced.

Land-use control has tended to be more effective when applied to artificial reservoirs, principally because in many countries these have been located away from intensive human activity. However, land-use controls may be

difficult to introduce as the creation of a large body of water may attract industry which will have effluent discharges. Reservoirs may promote intensive arable agriculture which utilises inorganic fertilisers and pesticides which may pollute the reservoir.

In many countries, standards have been or are being developed and enforced governing the quality of effluent that may be discharged into a river or standing body of water and in many countries, national bodies concerned with water are trying to shift the onus onto producers to treat wastewater prior to discharge - the 'polluter pays' principle. However, few countries have managed to enforce compliance with these standards and large-scale pollution continues. In many countries the penalties for exceeding quality standards are minimal and as the cost of installing treatment processes in the plant greatly exceed the accumulated cost of fines, there is little incentive for the producer to invest in treatment technology. This situation is often exacerbated by the time it takes for cases involving pollution to reach court, further reducing the real cost to the producer.

The rigorous enforcement of compliance with effluent quality standards backed up with adequate legislation which has penalties which reflect the severity of the pollution event will make a significant contribution to the improvement in surface water quality. However, positive influence should also be exerted to assist industry to employ discharge treatment in their plants. This may include awareness raising in the industry sector, technical advice concerning technology choice and may also involve other incentives

to industry, such as tax breaks or subsidies, to promote the use of treatment of effluents.

Sediments in surface waters also interact with pollutants in the aquatic environment and can become "reservoirs" of pollution. Where chemical contaminants, particularly metals, are in water there are commonly ion exchange reactions with minerals in the sediment and diffusion of chemicals into the sediment which leads to contaminant build-up. Where there is significant organic material in sediments or the base of streams, metals form organic complexes. These processes may remove contaminants from the water in the short-term, but may be released back into the aquatic environment at a later date, usually in response to a specific flood event. Thus stopping a polluting activity will not lead automatically to a rapid reduction in contaminant concentration in surface waters.

Conclusion

Water source and water resources protection are essential if high quality waters are to remain uncontaminated. Both groundwaters and surface waters are vulnerable to pollution and both require localised and larger-scale actions to prevent pollution of drinking-water sources. Surface waters are open to more immediate pollution and once a pollutant enters a surface water body, it is likely to move rapidly. This means that the pollutant will spread rapidly through the surface aquatic system, although it may make remediation easier, except where there is significant water-sediment

interchange.

Groundwater has more natural defences against pollution, however once it becomes polluted it is very difficult to remove the pollutant from the groundwater system and residence times of pollutants may be decades, centuries or longer. Different types of aquifer have differing degrees of vulnerability and thus have different protection requirements.

Both surface and groundwater resources are protected by defining land-use zones around them. This ensures that the establishment of potentially polluting activities is not allowed within a distance that would allow easy pollutant movement. Control of pollution is vital for water source and water resource protection and should be rigorously enforced.

References

Chilton, J., *Groundwater,* in Chapman. D., (ed) *Water Quality Assessments (2nd edition)*, Chapman and Hall, London, 1996.

Environment Agency, *Policy and Practice for the Protection of Groundwater*, Environment Agency, London 1996.

Foster, S.S.D. and Hirata, R. *Groundwater Pollution Risk Assessment*, CEPIS, PAHO/WHO, Lima 1988.

Newson, M. *Land, Water and Development*, Routledge, London, 1992.

Presentation Plan

Section	Key Points	OHP
Introduction	• prevention of contamination is important and preferable to treatment	**1**
	• this is achieved through: source protection; water resource management; good design and operation; and surveillance	
	• source selection is important, always select best source available	
	• sources should be assessed under worst case conditions	
	• contaminated sources can still be used	
Water Source Protection	• mixture of localised and broader measures	**2**
	• localised measures prevent contamination in immediate vicinity, sanitary completion measures	
	• broad scale measures prevent pollution of water resources and loss of water sources from distant pollution	
Groundwater	• natural state is very good microbiological quality	**3,4,5,6,7,8**

Groundwater Protection	• natural state is very good microbiological quality	**3,4,5,6,7,8**
	• chemical quality is sometimes less good	
	• natural removal of contaminants through attenuative processes	
	• once contaminated, removal is expensive and difficult	
	• different aquifers have different vulnerabilities	
	• groundwater protection zones define acceptable land uses around water sources to prevent contamination	
	• definition of zones for microbiological protection are easy, zones for chemical protection are more difficult	
	• shapes of zones vary and surface water-groundwater interactions affect zone shapes and extent	
Surface Water Protection	• surface water is very vulnerable to contamination from many sources and pollutant move rapidly through surface water bodies	**9,10,11,12,13**
	• surface water always requires treatment prior to consumption	
	• sources protected through land use control, intake	

	design and pollution control	
	• land use in immediate upstream vicinity of source should be restricted to non-polluting activities	
	• effluent control is important and stringent standards and end of pipe treatment are all required	
	• legislative support and awareness raising in industry are important	
Conclusions	• need source and resource protection to maintain high quality waters	
	• surface water is more vulnerable to pollution than groundwater	
	• pollutants move rapidly in surface water and surface water always requires treatment	
	• once contaminated, remedial action for groundwater is expensive and difficult	
	• control of land use is important for both groundwater and surface water	

Source Protection

- **Prevention of contamination is preferable and more sustainable than treatment**

- **Source selection is important**

- **Assess potential source of drinking-water under 'worst case' conditions**

- **Contaminated sources may still be used provided minimum treatment requirements are met**

Source Protection Measures

- **Localised:**

  sanitary well seal
  protected intakes

- **Large scale:**

  watershed management
  groundwater protection zones
  water resource management policies

Groundwater Definitions

Aquifer:

Rock or unconsolidated deposit containing water

Porosity:

The percentage of voids in a formation.

Permeability:

Measure of inter-connectedness of pores

Bulk permeability:

Flow through mass as a whole

Intrinsic permeability:

Rate at which rock will allow fluid to pass independent of fluid

Groundwater Protection Zones

- **Zones for land use control to prevent contamination**
- **Based on contaminant persistence and travel time**
- **Very high flows - possibly reduce travel time as increase attenuation**

50 DayIsochron:

- **For control microbiological contamination**

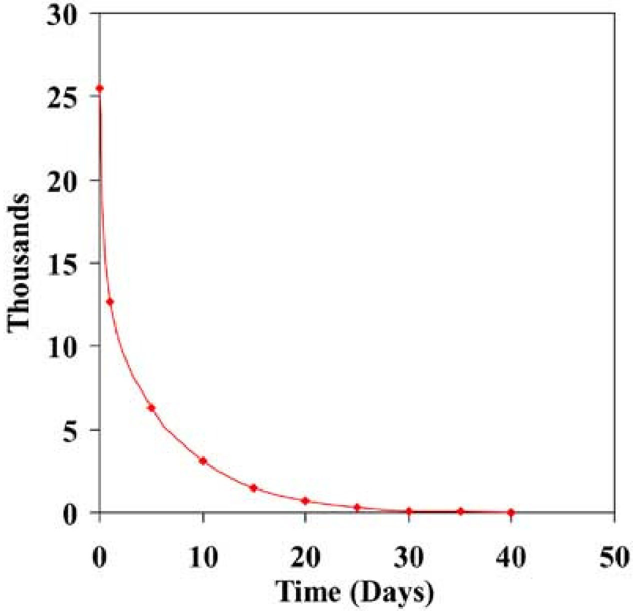
- **Most microbes die within 50 days in groundwater**

400 DayIsochron

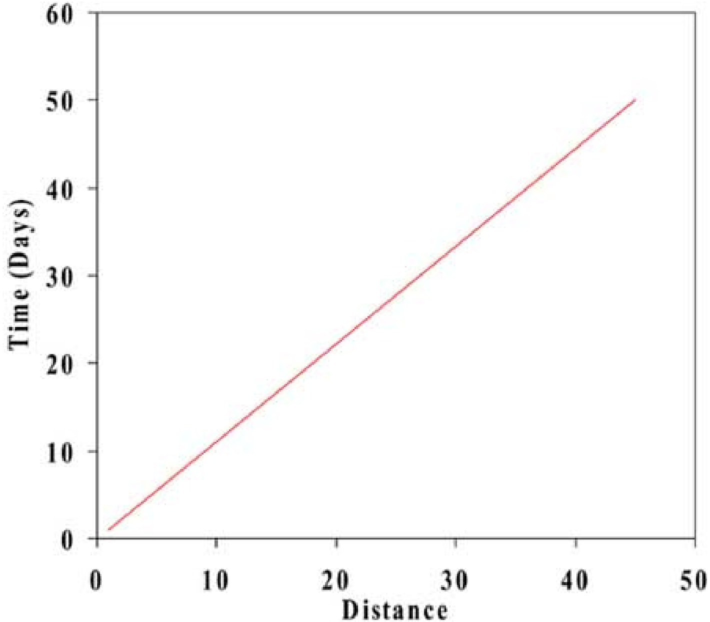
- **Used to control persistent chemicals**
An alternative is 25 per cent of the recharge area

Source Catchment

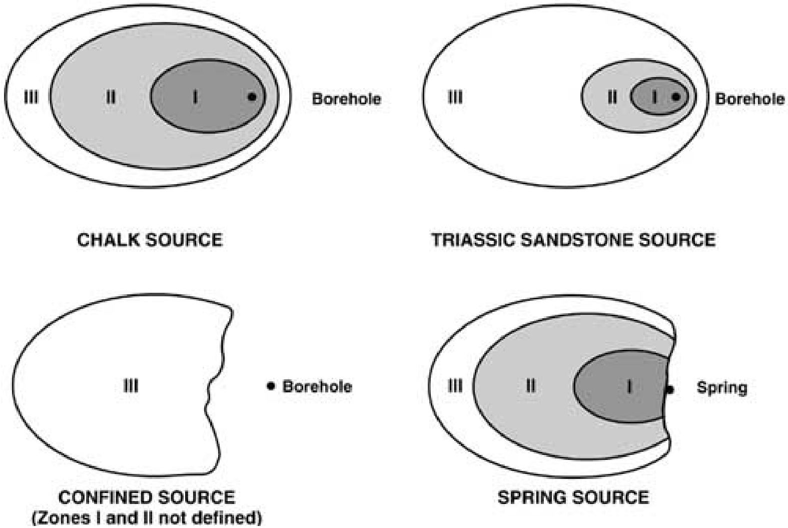
- **Protects the area of long-term annual recharge.**



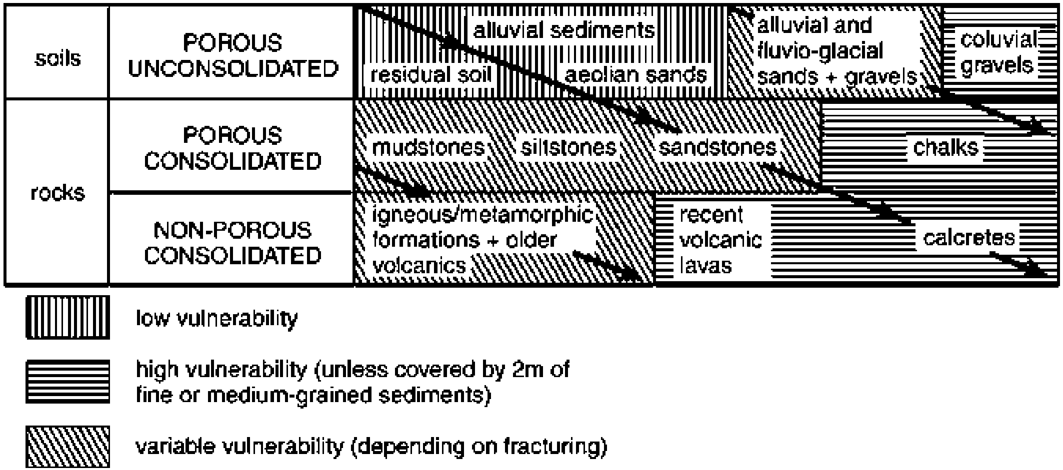
Organism Survival



Distance-time Curve



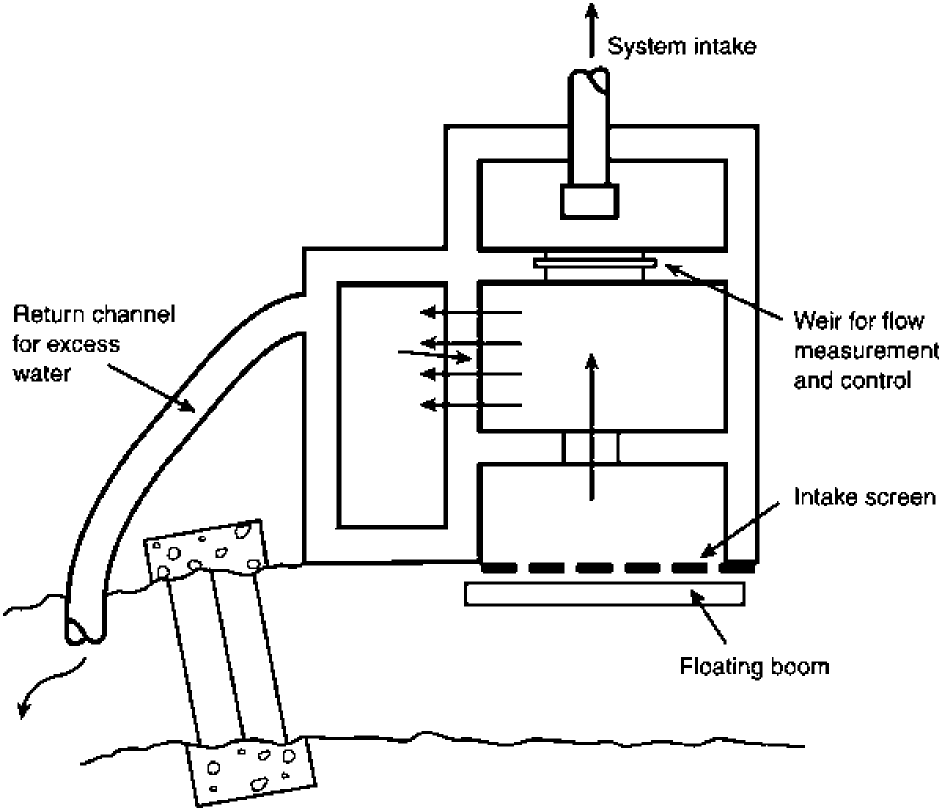
Examples of Protection Zones (NRA, 1992)



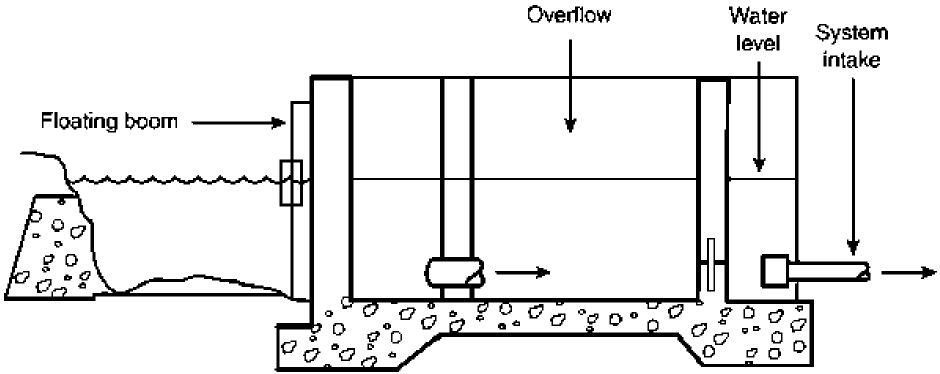
Simplified lithological classification of geological formation in terms of relative risk of groundwater pollution

Source: Foster, 1987

Protected River Intake


System intake
Weir for flow measurement and control
Return channel for excess water
Intake screen
Floating boom

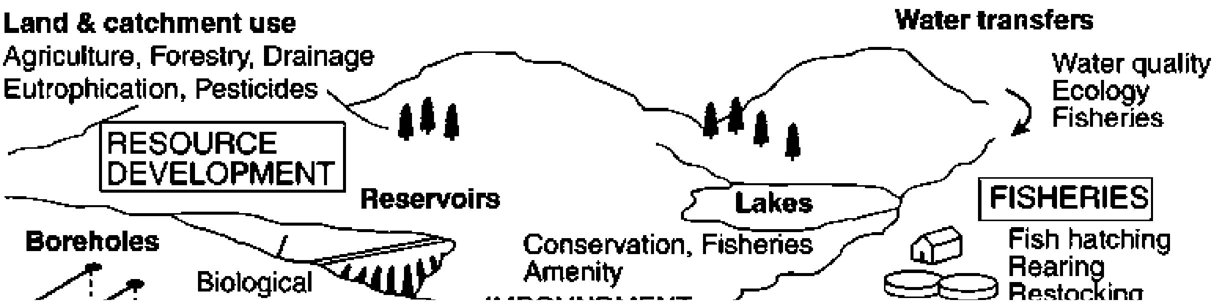
A. Plan view

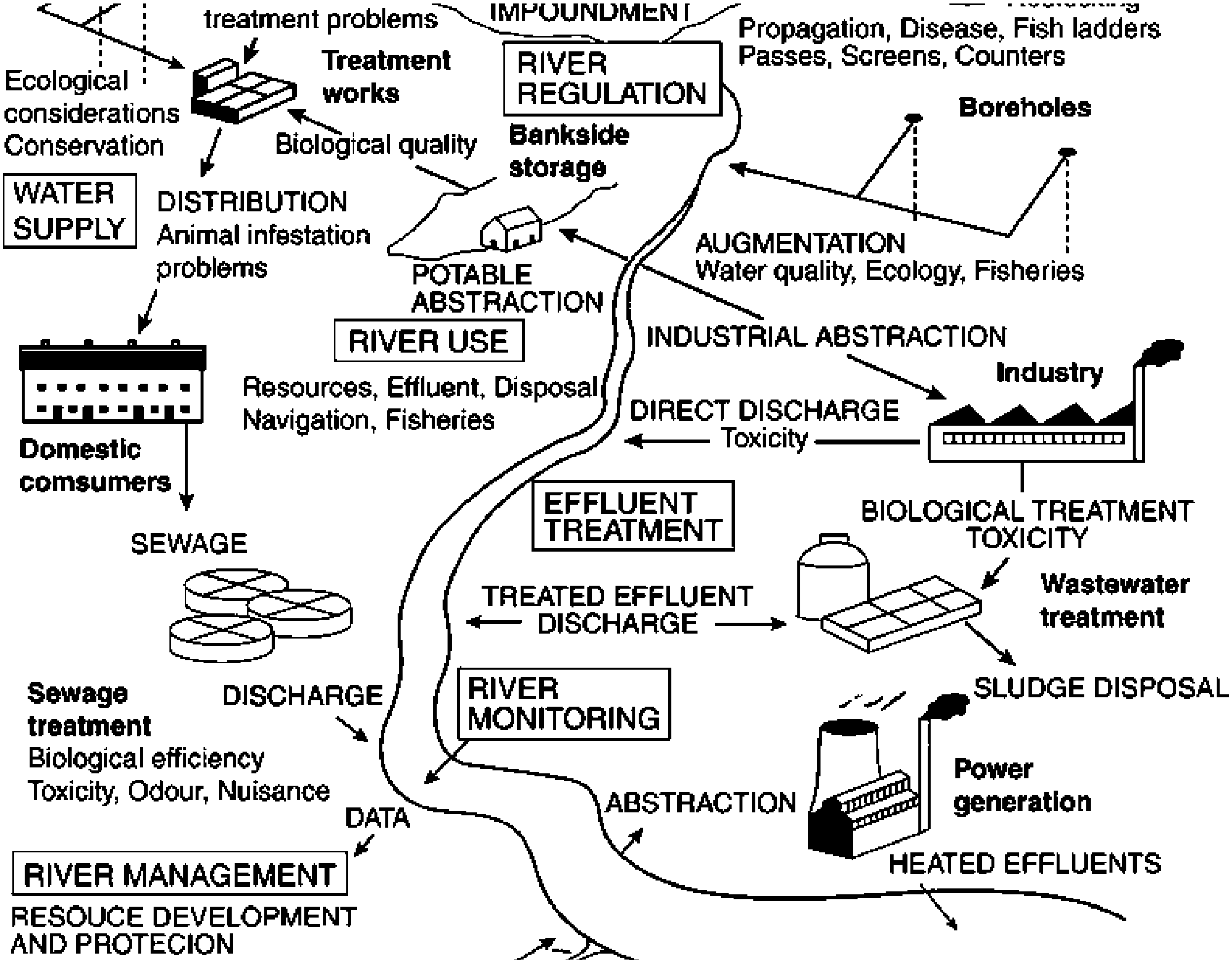


B. Cross Section

Water Resources Protection

- **Land use planning and control**
- **Environmental conservation and habitat protection**
- **Pollution control**





treatment problems
IMPOUNDMENT
Propagation, Disease, Fish ladders
Passes, Screens, Counters
Ecological
considerations
Conservation
Treatment
works
RIVER
REGULATION
Boreholes
Biological quality
Bankside
storage
WATER
SUPPLY
DISTRIBUTION
Animal infestation
problems
POTABLE
ABSTRACTION
AUGMENTATION
Water quality, Ecology, Fisheries
RIVER USE
INDUSTRIAL ABSTRACTION
Industry
Resources, Effluent, Disposal
Navigation, Fisheries
DIRECT DISCHARGE
Toxicity
Domestic
consumers
EFFLUENT
TREATMENT
BIOLOGICAL TREATMENT
TOXICITY
SEWAGE
Wastewater
treatment
TREATED EFFLUENT
DISCHARGE
SLUDGE DISPOSAL
Sewage
treatment
Biological efficiency
Toxicity, Odour, Nuisance
DISCHARGE
RIVER
MONITORING
Power
generation
ABSTRACTION
DATA
HEATED EFFLUENTS
RIVER MANAGEMENT
RESOUCE DEVELOPMENT
AND PROTECION

Model of Issues and Activities in Surface Water Management

Source: Newsom, 1994

Pollution Sources and Control

- **Land-based diffuse:**

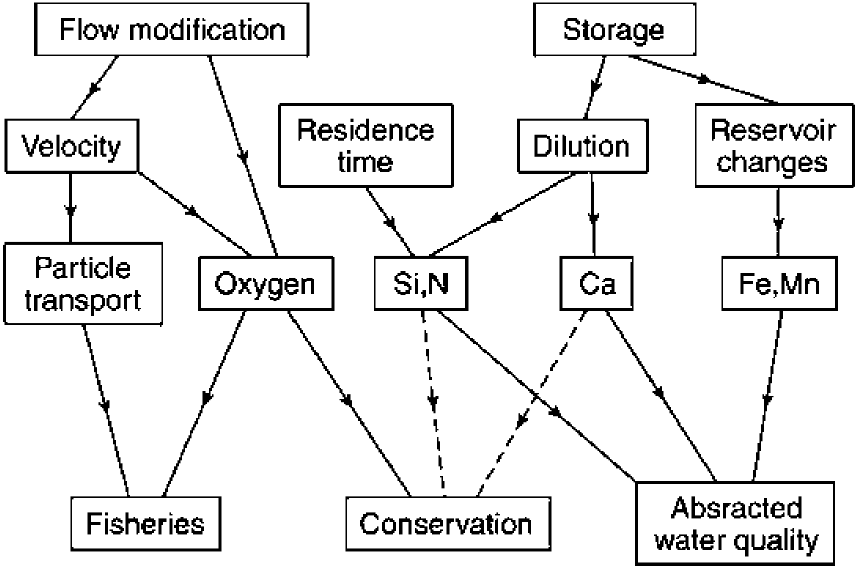
  land use control
  control on agrochemical use

- **Point source:**

  effluent quality standards
  enforce compliance

- **Air-borne particulate matter:**

  difficult to control
  international treaties on air pollution reduction



Impacts of Intermediate Reservoir Storage in Hydrology and Water Quality

Source: Newsom, 1994

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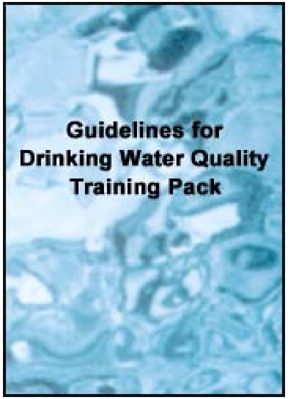

Guidelines for
Drinking Water Quality
Training Pack

Water Treatment

Session Objectives

- **To demonstrate the need for treatment of surface waters and some groundwaters for drinking purposes.**
- **To introduce the concept of the multiple barrier principle and to describe the more common and important key processes.**
- **To describe the function of each treatment process in treating drinking-water.**
- **To provide a basic outline on the selection of technology.**
- **The discuss the assessment of water treatment plants.**

Introduction

All surface water and some groundwaters require treatment prior to consumption to ensure that they do not represent a health risk to the user. Health risks to consumers from poor quality water can be due to microbiological, chemical, physical or radioactive contamination.

However, microbiological contamination is generally the most important to human health as this leads to infectious diseases which affect all populations groups, many of which may cause epidemics and can be fatal. Chemical contamination, with the exception of a few substances such as cyanide and nitrate, tends to represent a more long-term health risk. An example of this is nitrate which can cause methaemoglobinaemenia in babies. Substances in water which affect the clarity, colour or taste of water may make water objectionable to consumers and hence ability to recover costs. As many microorganisms are found associated with particles in water, physical contamination may also represent a health risk as it extends microbial survival.

Most treatment systems are designed to remove microbiological contamination and those physical constituents which affect the acceptability or promote microorganism survival - largely related to the suspended solids in the water. A disinfectant is nearly always included in treatment plants of any size. This is done for two main reasons: firstly it is added to inactivate any remaining bacteria as the final unit of treatment; and, more importantly,

to provide a residual disinfectant which will kill any bacteria introduced during storage and/or distribution.

The multiple barrier principle

Treatment processes usually function either through the physical removal of contaminants through filtration, settling (often aided by some form of chemical addition) or biological removal of microorganisms. It is usual for treatment to be in a number of stages, with initial pretreatment by settling or pre-filtration through coarse media, sand filtration (rapid or slow) followed by chlorination. This is called the multiple barrier principle.

This is an important concept as it provides the basis of comprehensive treatment of water and provides a system to prevent complete treatment failure due to a breakdown of a single process. For instance, with a system which comprises addition of coagulation-flocculation-settling, followed by rapid sand filtration with terminal disinfection, failure of the rapid sand filter does not mean that untreated water will be supplied. The coagulation-flocculation-settling process will remove a great deal of the suspended particles, and therefore many of the microorganisms in the water, and the terminal disinfection will remove many of the remainder. Provided the rapid sand filter is repaired reasonable quickly, there should be little decrease in water quality.

A key element in the multiple barrier principle is to ensure that the source of

water is protected and maintained at as high a quality as possible. This is sometimes easier for groundwater sources on a local scale, although there are obvious difficulties for both ground and surface water on a larger scale.

Treatment processes - advantages and disadvantages

There are many different treatment process available and whose suitability is a function of the source water quality, level of operator training and resources available for operation and maintenance. It is imperative that the selection of technology for treatment plants is done taking the above into consideration to ensure that they remain sustainable.

Prefiltration

As many secondary filtration processes, and in particular slow sand filtration, require low influent turbidities, some form of pretreatment to reduce suspended solids load is required. One way to achieve this is by using prefiltration of water through coarse media, usually gravel or coarse sand. Prefilters can have many different configurations: horizontal; vertical upflow; and vertical upflow-downflow. Vertical prefilters have become increasingly popular as they require far less land than horizontal prefilters and can take faster flow runs through them. An alternative are pressure filters, through which water is pumped at pressure to remove the suspended solids load.

Prefilters have an advantage in that they do not require chemicals, have limited working parts and are robust. They do however, require frequent cleaning and maintenance and are ineffective in removing fine particles, thus where the suspended solid load is primarily made up of silt and clay particles prefiltration is ineffective. Prefiltration is a physical process designed to remove suspended solids and therefore it's efficiency in removal of microorganisms is a function of the microbes associated with particles. Virus removal is poor and prefiltration is not effective in the removal of cysts or bacteria associated with fine particles.

Sedimentation

Sedimentation is the removal of suspended solids through the settling of particles moving through a tank at a slow rate. There are a number of forms of sedimentation. In water treatment plants treating source water a high proportion of suspended solids of coarser grades (e.g. sand and coarse silt) a grit chamber may be used to remove the largest particles through simple sedimentation. In this process, water is passed through a tank at a slow rate and suspended solids fall out of suspension. In small supplies, simple sedimentors may also be used, which functioning in a similar fashion to grit chambers, although with a slower rate of water throughflow. Simple sedimentation will not remove fine grained particles because the flow rates remain too high and the retention time is insufficient. A further common fault with simple sedimenters is that design flow rates are rarely achieved in practice and a certain element of 'short-circuiting' can occur unless

construction, operation and maintenance is very careful.

As a result of the drawbacks in simple sedimentation, it is common to find that the sedimentation process is enhanced through the addition of chemicals - or coagulation. Coagulants carry a charge and therefore attract charged clay particles. The particles begin to aggregate and form 'flocs'. Once the flocs reach a critical mass, they sink to the bottom of the settler. The outlet of the sedimenter is generally around the top of the structure, thus the clear water is removed by a surface channel. This system can be further refined with the use of modular or plate settlers which reduces the time require for settling by providing a wider surface area for aggregation of particles.

The most commonly used coagulants is aluminium sulphate, although there are other coagulants available including ferric salts (sulphates and chlorides) and polyelectrolytes. Coagulants are dosed in solution at a rate determined by raw water quality near the inlet of a mixing tank or flocculator. It is essential that the coagulant is rapidly and thoroughly mixed on dosing, this is may be achieved through the use of a hydraulic jump. The water then passes into the settler to allow aggregation of the flocs. Increasing use is now being made of synthetic polymer compounds or polyelectrolytes. As these are highly charged, there is a rapid increase in the formation of flocs, particularly where clay makes up a large proportion of the suspended solid load.

The advantages of the coagulation is that it reduces the time required to settle out suspended solids and is very effective in removing fine particles which are otherwise very difficult to remove from water. Coagulation can also be effective in removing protozoa, bacteria and viruses, particularly when polyelectrolyte is used, as the highly charged coagulant attracts the charged microorganisms into the flocs. Coagulation can also be effective in removing by precipitation certain contaminants such as lead and barium.

The principle disadvantages of using coagulants are the cost and the need for accurate dosing, jar testing and dose adjustment and frequent monitoring. Coagulants can be expensive to buy (particularly polyelectrolyte) and need accurate dosing equipment to function efficiently. Staff need to be adequately trained to carry out jar tests to determine coagulant dosage.

Sand Filtration

Sand filtration can be either rapid or slow. The difference between the two is not a simple matter of the speed of filtration, but in the underlying concept of the treatment process. Slow sand filtration is essentially a biological process whereas rapid sand filtration is a physical treatment process.

Slow sand filters have an advantage over rapid sand filters in that they produce microbiologically "clean" water which should not require disinfection to inactivate any bacteria, although the addition of a disinfectant

to provide a residual for the distribution system is still advisable. However, because of their slow flow rate, slow sand filters require large tracts of land if they are to supply large populations and can be relatively labour intensive to operate and maintain. As the reestablishment of the schumtzdecke takes several days, the plant has to have sufficient capacity to supply the water demand when one or more filters are out of action.

Rapid sand filtration is now commonly used worldwide and is far more popular than slow sand filtration. The principal factor in this decision has been the smaller land requirement for rapid sand filters and lower labour costs. However, rapid sand filters do not produce water of the same quality as slow sand filters and a far greater reliance is placed on disinfection to inactivate bacteria. It is also worth noting that rapid sand filters are not effective in removing viruses.

Slow sand filters

Slow sand filters operate at slow flow rates, 0.1 - 0.3 metres per hour. The top layers of the sand become biologically active by the establishment of a microbial community on the top layer of the sand substrate. These microbes usually come from the source water and establish a community within a matter of a few days. The fine sand and slow filtration rate facilitate the establishment of this microbial community. The majority of the community are predatory bacteria who feed on water-borne microbes passing through the filter.

The microbial community forms a layer called the schumtzdecke and can develop up to 2cm thick before the filter requires cleaning. Once the schumtzdecke becomes too thick and the rate of filtration declines further it is scraped off, a process done every couple of months or so depending on the source water. Once this has been carried out, the slow sand filter will not be fully functional for another 3 to 4 days until a new schumtzdecke has developed, although this procedure can be speeded up by seeding the filter with bacteria from the removed schumtzdecke. Slow sand filtration is extremely good at removing microbial contamination and will usually have no indicator bacteria present at the outlet. Slow sand filters are also effective in removing protozoa and viruses.

Slow sand filters require low influent turbidity, below 20TU and preferably below 10TU. This means that efficient pretreatment is required to ensure that the filters do not become overloaded. Slow sand filters can cope with shock turbidities of up to 50TU, but only for very short periods of time before they block. The sand used in slow sand filters is fine, thus high turbidities cause the bed to block rapidly and necessitates more frequent cleaning and therefore greater time out of action. Nevertheless, slow sand filters are still used in London and were relatively common in Western Europe until comparatively recently and are still common elsewhere in the world. The move away from slow sand filtration has largely been a function of rising land prices and labour costs which increased the cost of slow sand filter produced water, where this is not the case, slow sand filters still

represent a cost-effective method of water treatment.

Rapid sand filters

Rapid sand filters work at much higher rates of flow (up to 20 meters per hour) and essentially rely on physical removal of suspended solids, including any floc carried over from the settlers. Although rapid sand filters achieve some reduction in microbial populations in water as it removes particles to which bacteria are attached, it is not a biological treatment and the use of a terminal disinfectant is vital to ensure that bacteria in the water have been inactivated. Rapid sand filters require frequent cleaning (daily or twice daily) which is achieved through backwashing filters with clean water to re-suspended the sediment. Cleaning takes relatively little time and the filters can be put back into operation immediately.

Rapid sand filters are far smaller than slow sand filters and are commonly employed in 'batteries'. The rapid flow rate through these filters means that demand can be more easily met from smaller plants. Rapid sand filters do not require low influent turbidities, as they are essentially a physical treatment process, although higher suspended solids loads will result in more frequent cleaning. Backwashing is usually rapid and filters are not out of commission for mare than a matter of minutes. Cleaning and operation can be largely mechanised and air scour is commonly employed to make backwashing more effective. With the small land requirement, several rapid sand filters can be accommodated in small area and thus it is easy to

maintain capacity to meet demand when filters are being cleaned.

Disinfection

Only a very brief discussion of disinfection is included here for completeness sake and for further information please refer to session XIV of the Teaching Pack or to Chapter 6 of Volume 1 of the Guidelines and Chapter 6 of Volume 3.

All water supplies should be disinfected in order to protect public health. Disinfection inactivates any remaining bacteria in the water after previous treatment steps and provides a residual disinfectant to inactivate bacteria introduced by any subsequent ingress of contaminated water during storage or distribution.

At present, the principal disinfectant used worldwide is chlorine, although alternatives are being increasingly investigated and process such as ozonation are becoming more important in industrialized countries. It is important to note that all disinfectants produce by-products and that the greater knowledge about the by-products formed from the use of chlorine because it is this most widely used disinfectant should not compromise it's use. It is also important that disinfection of water supplies is never compromised because of a risk of potential health effects from by-products in the final water. Any health impacts from chemical contamination is likely to be long-term, whereas the absence of disinfection puts the consumers at

risk from infectious diarrhoeal disease.

Other Treatment Processes

The above treatment process are all designed to make drinking-water safe by the removal of microorganisms and suspended solids. However, drinking-water, particularly from groundwater sources, may also contain chemical contaminants which must be removed. Generally the removal of chemicals from water is more difficult and much more expensive than removing microbiological or physical contaminants. Basic filtration and coagulation techniques are not generally effective for the majority of chemicals.

As there are many different chemicals which could be dealt with, a few relevant examples will be provided. Iron can be a major constituent of both ground and surface waters (where it is commonly associated with bacteria and algae). Although iron does not represent any health risk, it causes problems of acceptability of the water as many consumers find the colour off-putting and because it stains clothes. The principal method of removing iron from water is through aeration or oxidation of the Fe^{2+} to the Fe^{3+} species. This is easily achieved by flowing the water over a simple cascade and followed by sedimentation. Note aeration is also used for waters known to be anoxic or oxygen deficient.

A variety of processes are used for the removal of organic and inorganic contaminants including ion exchange and precipitation. For instance, fluoride may be removed through coagulation with lime or by ion exchange using calcinated burnt bone or activate alumina. Granulated activated carbon (GAC) is commonly used for pesticide removal through adsorption. This is expensive but unfortunately no other process appears to work effectively and therefore GAC remains the sole option.

Selecting Technology

When selecting technology and systems of treatment it is vital that as full a picture as possible of the source water quality is available. It is important to know what is in the water before trying to design appropriate treatment systems. It is equally important to maintain a thorough monitoring programme through the plant to ensure that each stage of treatment is working effectively and efficiently.

All waters may need treatment before they are fit for human consumption, although surface waters tend to be more vulnerable to contamination than groundwater. All surface waters will require treatment prior to consumption. Furthermore, all water supplied through distribution systems should be disinfected to provide a residual disinfectant which provides ongoing protection from bacterial growth and survival.

Presentation Plan

Section	Key points	OHP

Introduction	• need to treat all surface waters and some groundwaters	
	• contamination may be microbiological, chemical or physical	
	• microbiological contamination is most important as it causes highly infectious disease with short-term impacts	
	• chemical contamination tends to have longer term effects on health	
	• suspended solids affect microbial survival and the acceptability of water	
	• always disinfect water supplies and maintain a residual in the water for protection against contamination during distribution and storage	
Multiple Barrier Principle	• need to have more than a single process during treatment	**1**
	• prevents breakdown in one process leading to complete treatment failure	
	• source must be well protected	
Treatment processes	• many processes available, the suitability of each is a function of source quality, operator capacity and financial resources	**2,3,4,5**
	• technology selection must be made on the basis of the	

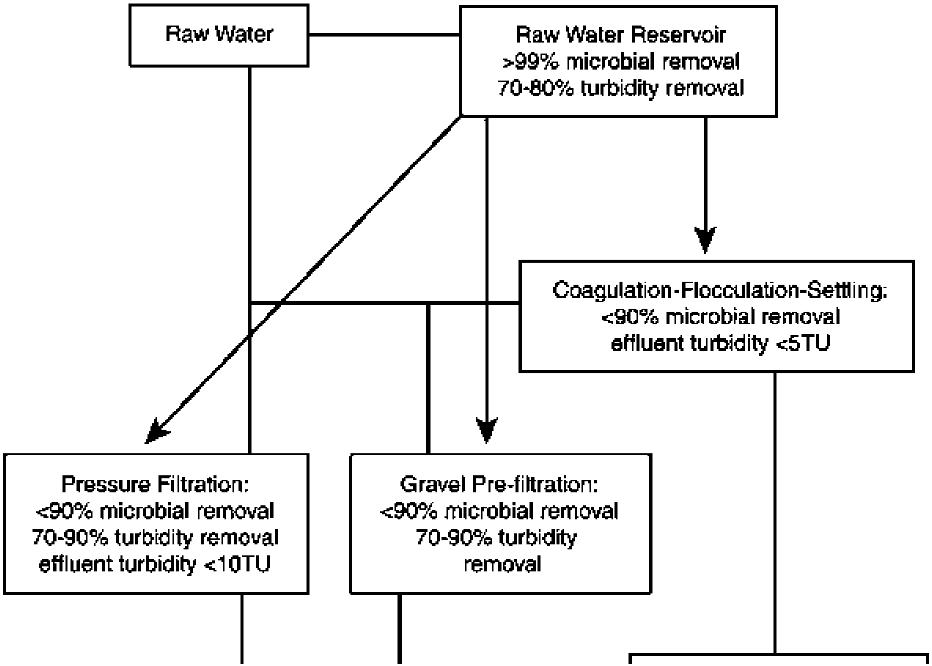
	• technology selection must be made on the basis of the above to ensure sustainability	
	• often need to reduce turbidity before treating water as this may interfere with treatment	
	• prefiltration is a physical process which removes suspended solids	
	• prefilters can be horizontal, vertical upflow or vertical upflow-downflow	
	• main advantage is limited working parts and doesn't use chemicals	
	• disadvantages include poor ability to remove fine material, microbial removal poor and may need frequent cleaning	
	• sedimentation is achieved by the settling of particles in slow moving water	
	• simple sedimenters do not use chemical coagulants and are not effective in removing fine material	
	• settling is improved through addition of coagulants to form larger aggregates which speeds up settling and removes fine material	
	• modular and plate settlers improve settling efficiency	
	• alum is the most common coagulant, others include polyelectrolytes and ferric salts such as sulphate and chloride	

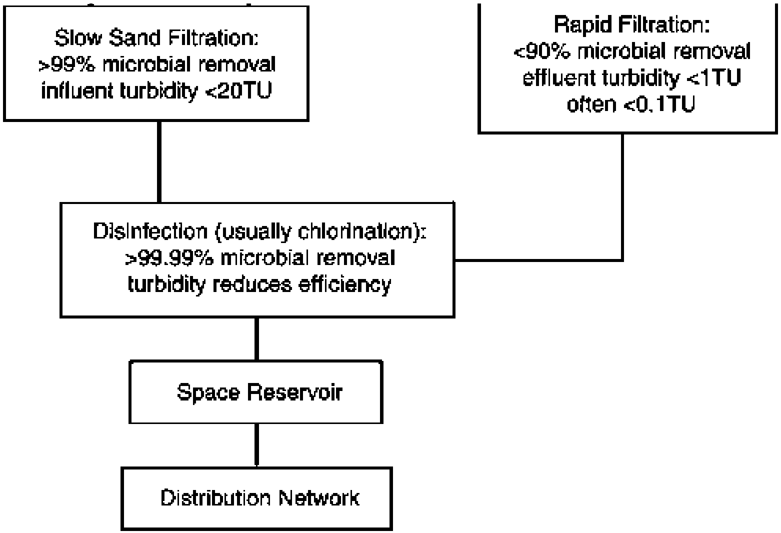
	• advantages include removal of fine particles, removal of some viruses, quick, compact	
	• disadvantages include expense, need for good monitoring capacity, need trained operators	
Treatment processes	• sand filtration can be rapid or slow	**6,7**
	• slow sand filtration is a biological process and rapid sand filtration a physical process	
	• slow sand filters a biologically active top layer called the schumtzdecke which is composed of predatory bacteria	
	• schumtzdecke kills bacteria and viruses	
	• require cleaning at every 2 months, take 3-4 days to recover	
	• rapid sand filters work at much faster rates and remove suspended solids	
	• advantages of slow sand filtration include production of good quality water, relatively simple to operate	
	• disadvantages include large land requirement, labour intensive, requires low turbidity water	
	• advantages of rapid sand filtration include small land requirement	
Treatment	• assessments of treatment plants may be carried out for a	**8,9**

plant assessments	number of different reasons	
	• routine assessments often carried out by water suppliers to ensure performance is efficient and optimised	
	• assessments may also be undertaken when there is a failure in water quality or a failure to produce water of adequate quality	
	• assessments involve the evaluation of each unit process to ensure that it performs efficiently and to identify any process failures and causes of failures	
	• assessments should also evaluate the suitability of combinations of technologies (e.g. sometimes find simple sedimenters combined with slow sand filters when turbidity was relatively high - led to failure)	
	• assessments should be linked to performance optimisation	
Conclusion	• both surface and groundwater may require treatment before distribution	
	• source water quality (and likely variations) should be known before selecting technologies	
	• technologies should be used which reflect capacity to	

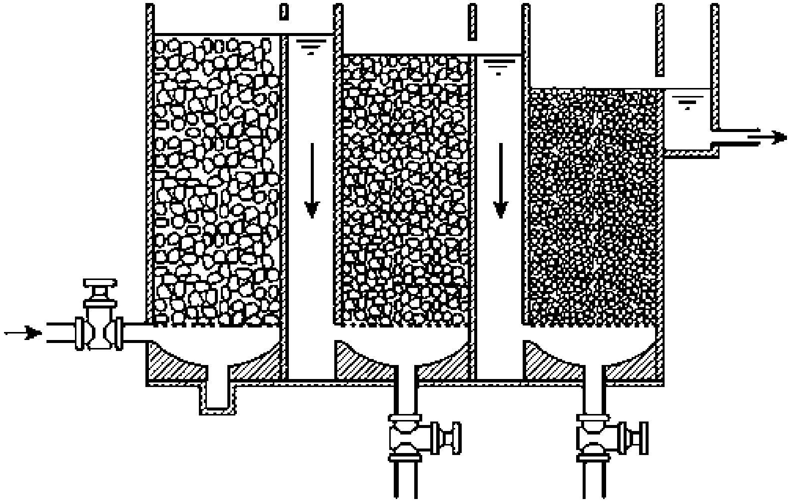
	operate the plant and which provide adequate treatment	
	• a multiple barrier principle should always be used when treating water	
	• source protection is also vital	

NB: OHPs 8 and 9 may be used when discussing water treatment plant monitoring and assessment

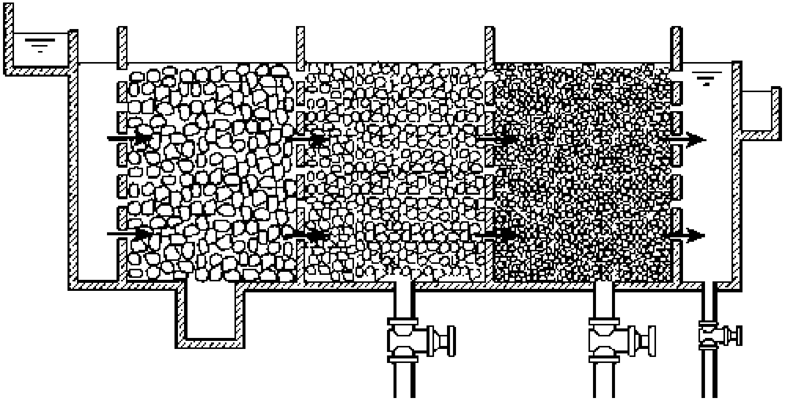




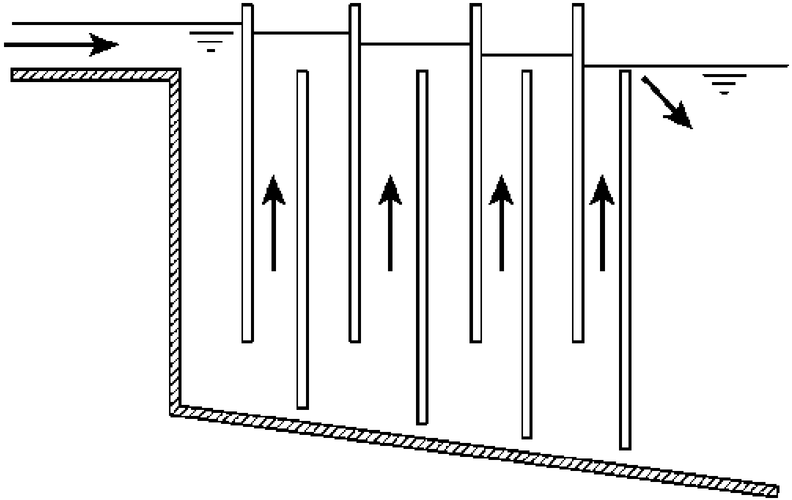
The Multiple Barrier Principle of Water Treatment



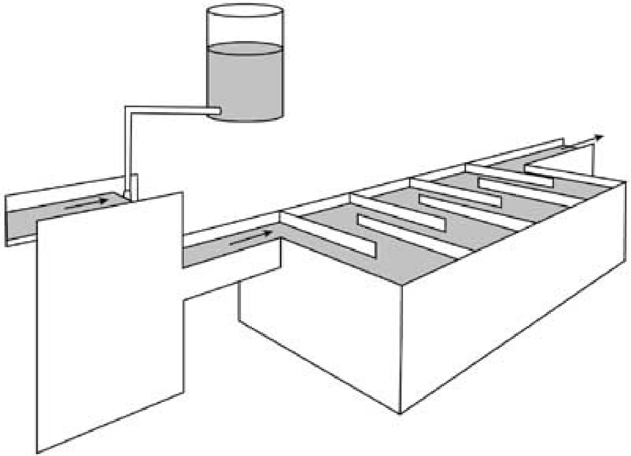
Upflow-Downflow Prefilter



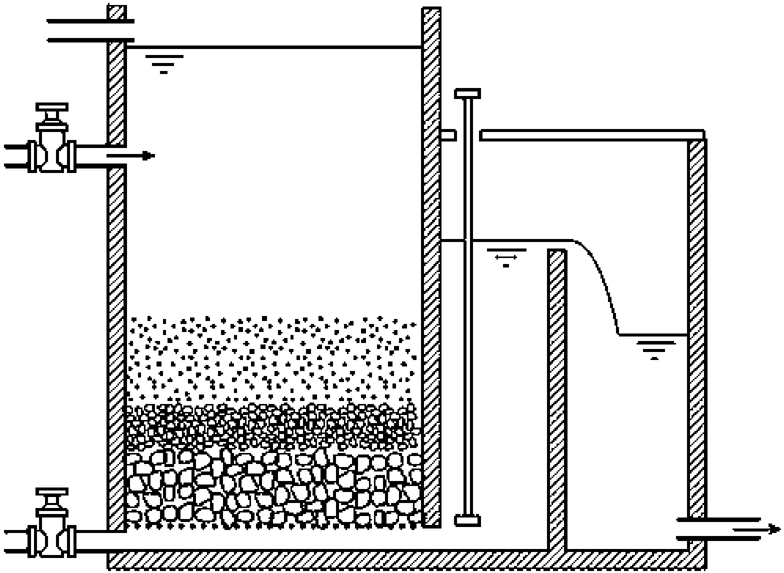
Horizontal Flow Prefilter



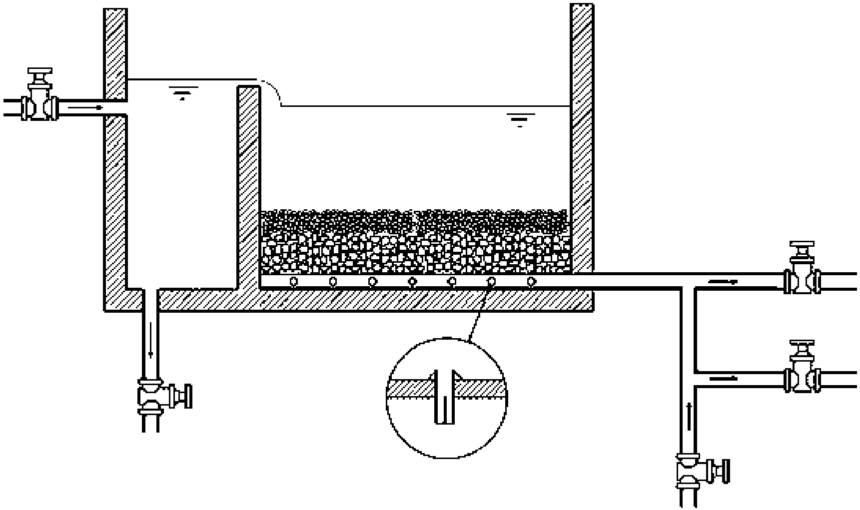
Flocculator



Coagulant Dosing



Slow Sand Filter



Rapid Sand Filter

Water Treatment Plant Assessments

When and why the should be carried out:

- **Routine assessment of operational efficiency and state of equipment**
- **When contamination is found**
- **When disease outbreaks occur**
- **If disinfection dosing requirements suddenly change**

Water Treatment Plant Assessments Parameters

Raw Water:

turbidity, pH, alkalinity, coliforms, major ions, nutrients, known problem substances

Coagulation-flocculation-settling:

turbidity, pH, residualaluminum, residual acrylamide, coliforms

Prefiltration:

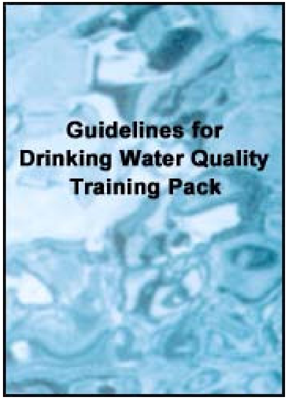
turbidity, pH, coliforms

Sand filtration (rapid/slow):

turbidity, pH, coliforms

Disinfection:

residual (usually chlorine), pH, turbidity, coliforms (thermotolerant and total)


Guidelines for
Drinking Water Quality
Training Pack

Disinfection

Session Objectives

- **To introduce the principal disinfectants that may be used and highlight key advantages and disadvantages of each**

- **To emphasise the use of chlorination for routine disinfection.**

- **To describe the process of chlorination and discuss the concepts of breakpoint chlorination, chlorine demand and outline basic chlorine chemistry.**

- **To discuss the types of chlorine available and how these may be used for routine disinfection.**

Introduction

All water supplies should be disinfected. This is aimed both at inactivating remaining bacteria before distribution and providing a residual disinfectant to inactivate bacteria introduced by any subsequent ingress of contaminated water during storage or distribution. At present, the principal disinfectant used worldwide is chlorine, although alternatives are being increasingly investigated and process such as ozonation are becoming more common.

Chlorine is generally the disinfectant of choice as it is reasonably efficient, cheap and easy to handle. In all but the smallest water treatment plants, chlorine is added to water as either in aqueous solution (calcium hypochlorite or sodium hypochlorite) or chlorine gas. Smaller supplies may use tablets of hypochlorite.

Other disinfectants include ozone, ultraviolet light and iodine. These all have disadvantages. UV is not a particularly effective disinfectant and it is difficult to expose water for sufficient time for disinfection to be effective. Neither ozone or UV provide a residual disinfectant and therefore offer no protection against recontamination in distribution. To overcome this, in some water supplies booster ozonation stations are set up along the distribution network.

Both iodine and ozone are carcinogenic. There are also significant health and safety concerns, for operators, regarding the generation and application of

ozone and chlorine (especially in the gaseous form). Iodine can also lead to thyroid problems with pregnant women and is generally more toxic than chlorine.

Selection of disinfectant

Under most circumstances, overwhelming factors will dictate selection of disinfection method. The most common major factors are: availability, cost of disinfectant, logistics (especially transport costs), and cost/availability of equipment. Under the majority of circumstances chlorine in one of its forms has been found to be the disinfectant of choice. The choice of which form of chlorine will again largely be determined by availability, cost and transport.

Chlorine

Chlorine is an effective disinfectant where water is not turbid (cloudy) and the pH of the water to be treated is not alkaline, for instance not above pH 8.0. However, most natural waters have a pH below 8.0 and thus disinfection is rarely compromised by pH.

Chlorine chemistry

Chlorine, whether in the form of pure chlorine gas from a cylinder, sodium hypochlorite or calcium hypochlorite in any of its presentations, dissolves in water to form hypochlorous and hydrochloric acids. Chlorine dioxide,

however, does not dissolve in water.

The reaction of chlorine in water follows the reaction shown below:

$$Cl_2 + H_2O \rightarrow HOCl + HCl$$

Hydrochloric acid dissociates in turn to form hydrogen and chloride ions

$$HCl \rightarrow H^+ + Cl^-$$

Hypochlorous acid however dissociates only partially

$$HOCl \Leftrightarrow H^+ + OCl^-$$

It is undissociated hypochlorous acid which acts as a disinfectant. The equilibrium between undissociated hypochlorous acid, hydrogen ions and hypochlorite ions depends on pH. At high pH (alkaline conditions, pH greater than 8), the dissociated forms predominate and at low pH (acidic conditions) undissociated hypochlorous acid predominates. For this reason disinfection with chlorine is more efficient at lower pH values and a pH of less than 8 is recommended for disinfection. Pure chlorine gas from a cylinder tends to decrease the pH of the water slightly; hypochlorite tends to increase water pH a little.

Formation of combined chlorine is due to a sequence of reactions. Hydrogen

in ammonia is progressively replaced by chlorine as follows:

NH_3	$\rightarrow$ $NHCl$	$\rightarrow$ $NHCl_2$	$\rightarrow$ NCl_3
ammonia	monochloramine	dichloramine	nitrogen trichloride

Where it is desired to produce monochloramine as a more stable, but less efficient disinfectant, the two chemicals may be dosed in appropriate proportions.

$$NH_3 + Cl_2 = NH_2Cl + HCl$$

If a large chlorine dose is applied (relative to ammonia), as is practised in breakpoint chlorination, then nitrogen is formed.

$$2NH_2Cl + Cl_2 \rightarrow N_2 + 4HCl$$

Chlorine demand

The total amount of chlorine which will react with both compounds like iron and manganese and with organics and ammonia is referred to as the chlorine demand. The chlorine demand of different waters can vary widely.

Chlorine demand is the difference between the amount of chlorine added to the water (the chlorine dose) and the total chlorine detectable in the water. The chlorine demand for some waters, for instance some river waters, can

increase dramatically, particularly after heavy rain.

Breakpoint chlorination

The type of chlorine dosing normally applied to piped water supply systems is referred to as breakpoint chlorination. Sufficient chlorine is added to satisfy all of the chlorine demand and then sufficient extra chlorine is added for the purposes of disinfection. Figure 1 shows the breakpoint chlorination curve. It indicates the effect of adding more chlorine to water which contains an initial ammonia nitrogen content of 1 mg/l.

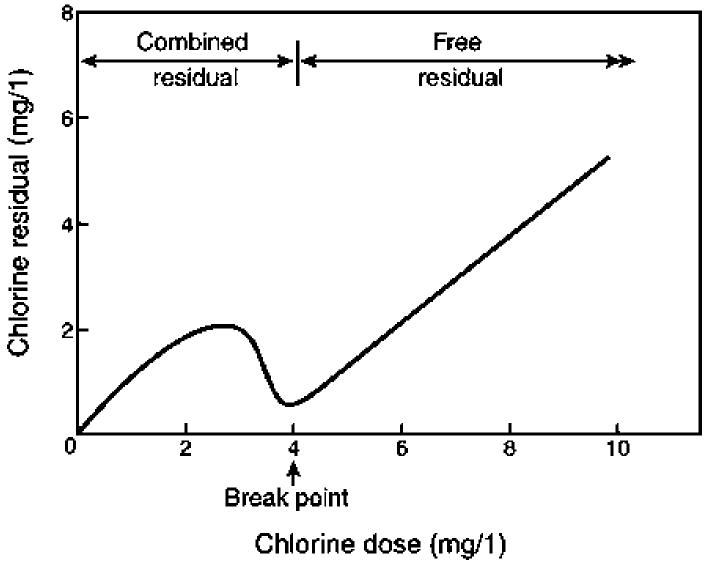


Figure 1. Breakpoint chlorination. Diagram taken from Tebbutt T.H.Y., 1992

The initial rise in residual is predominantly monochloramine (combined chlorine residual). The subsequent fall with further addition of chlorine is due to the decomposition of monochloramine to form nitrogen (the chlorine detected in this phase is also combined residual).

Finally the oxidation of ammonia is complete and any additional chlorine will cause an equal increase in the free chlorine residual.

Contact time

Disinfection with chlorine is not instantaneous. Time is required in order that any pathogens present in the water are inactivated.

The time taken for different types of microbes to be killed varies widely. In general, amoebic cysts are very resistant and require most exposure. Bacteria, including free-living *Vibrio cholerae* are rapidly inactivated by free chlorine under normal conditions. For example, a chlorine residual of 1mg/l after 30 minutes will kill schistosomiasis cercariae, while 2mg/l after 30 minutes may be required to kill amoebic cysts. Thus it is important to ensure that adequate contact time is available before water enters a distribution system or is collected for use.

Contact time in piped supplies is normally assured by passing the water, after addition of chlorine, into a tank from which it is then abstracted. In small community supplies this is often the storage reservoir (storage tank). In larger systems purpose-built tanks with baffles may be used. These have the advantage that they are less prone to "short circuiting" than simple tanks.

The pH of the water also affects the efficiency of chlorination and contact time is therefore also related to pH.

Chlorine residual

Chlorine persists in water as 'residual' chlorine after dosing and this helps to minimize the effects of re-contamination by inactivating microbes which may enter the water supply after chlorination. It is important to take this into account when estimating requirements for chlorination to ensure residual chlorine is always present.

The level of chlorine residual required varies with type of water supply and local conditions. In water supplies which are chlorinated there should always be a minimum of 0.5 mg/l residual chlorine after 30 minutes contact time in water.

Where there is a risk of cholera or an outbreak has occurred the following chlorine residuals should be maintained:

- At all points in a piped supply 0.5mg/l
- At standposts and wells 1.0mg/l
- In tanker trucks, at filling 2.0mg/l

In areas where there is little risk of a cholera outbreak, there should be a chlorine residual of 0.2 to 0.5 mg/l at all points in the supply. This means that a chlorine residual of about 1mg/l when water leaves the treatment plant is needed.

Problems of taste and odour

The taste of chlorine in drinking water may lead the population to reject a source of water which is actually safe to drink. They may then choose to use a better-tasting source of water which may in fact present a greater health risk. Chlorinous tastes in water are most often due to over-dosing or the presence of chlor-phenols.

Over-dosing may be due to error (which should be prevented by proper monitoring and control); may be deliberate (for instance, in response to contamination of the supply, which should be corrected as soon as possible and chlorine levels returned to normal); or may be due to high-level dosing to ensure adequate concentrations in remote parts of the distribution network (in this case consideration should be given to re-chlorination during distribution).

Chlor-phenols are formed where chlorine reacts with phenolic substances in water. These may be derived from algae, thus chlor-phenol formation is more common where the source is surface water than when groundwater sources are used. Chlor-phenols have a very strong chlorinous taste and very small amounts of chlorine can therefore give rise to very strong tastes. Problems with chlor-phenols are often transient and are best overcome by improving the intake and source.

Although chlorine itself can give rise to problems of taste and odour, chlorination can also help to improve taste and odour by the reduction of organic materials and iron.

As disinfection with chlorine is less effective in turbid water, water to be chlorinated should be clarified. This can be done by natural filtration as is the case with groundwater from wells and springs, or by filtration during water treatment. Filtration should also remove the cysts and eggs of protozoa and helminths which are resistant to chlorine.

Types of chlorine

Chlorine is available in various forms, including calcium hypochlorite, sodium hypochlorite and as pure chlorine gas in cylinders.

Calcium hypochlorite (chlorinated lime, tropical bleach, bleaching powder, 'HTH') is a powder containing between 30 and 70 per cent available chlorine. It must be stored carefully to prevent deterioration, and although it can cause burns, is generally safe to handle and transport. The Capital (equipment) costs of using calcium hypochlorite for disinfection are generally low. Calcium hypochlorite is most commonly used in solution for the disinfection of rural and small community water supplies and in diffusion hypochlorinators or in tablet form for household use.

Sodium hypochlorite (including household bleaches) is a solution. Sodium hypochlorite solutions contain about 1 to 18 per cent chlorine and are thus mostly water. The solution must be stored carefully to prevent deterioration, it can cause burns and is inefficient to transport, since it is mostly water. Sodium hypochlorite is most commonly used for disinfection in the home

and in water supplies where transport of the solution is not a problem.

Pure chlorine gas in cylinders, is used widely. Specialized transport, handling and dosing equipment are needed. However, as chlorine in cylinders is not normally subject to deterioration it is an efficient means of storing and dosing chlorine. Leaks of chlorine gas are very dangerous and installations storing cylinders should be well designed, monitored and maintained. Chlorine in cylinders is most commonly used for dosing at water treatment plants, at the head of wells from which water is mechanically pumped and at re-chlorination plants in large distribution networks.

For more detail on the technologies of chlorination please refer to Volume 3 of the Guidelines.

Chlorine dioxide

Chlorine dioxide is a more powerful oxidizing agent than chlorine, the disinfectant action of which is less pH-dependent than chlorine. It leaves a long-lasting residual. However, chlorine dioxide is an inefficient disinfectant for viral agents and therefore its use is limited.

Chlorine dioxide is mainly used for the control of tastes and odours. It does not combine with ammonia to a significant extent and therefore is more efficient than chlorine in waters with raised levels of ammonia.

Chlorine dioxide is unstable and must be generated on-site by the action of chlorine or an acid on sodium chlorite. In general the two chemicals are dosed together into the water; this process requires constant, vigilant monitoring and control. Chlorine dioxide is much more expensive than chlorine.

Iodine

Where water is not turbid, iodine is an effective disinfectant and is more stable than chlorine in storage. Iodine is mostly used for disinfecting small volumes of water for personal use. It is generally too costly for dosing into community water supplies. Iodine reacts less with organic matter than chlorine and does not react with ammonia.

A dose of two drops of a 2 percent solution of iodine in ethanol, per litre of clear water has been recommended for disinfecting small volumes of water for personal use. However, 1-2 mg/l with a contact time of not less than 30 minutes is normally recommended for public water supplies. Most people begin to detect the taste and odour of iodine at concentrations in the range 1-2 mg/l.

Iodine in solid form is easy to store and deteriorates less rapidly than chlorine. If dissolved in ethanol however, iodine will deteriorate rapidly. Stable iodine compounds for dosing into water supply systems, such as tetraglycine potassium tri-iodide are available as tablets.

Iodine is rarely appropriate as disinfectant for long-term use in community water supplies, especially because of its cost. Nevertheless, because of its stability and effectiveness, it is very useful for disinfection of drinking water, especially in small volumes in emergency, or disaster situations.

At high doses (for instance above 4 mg/l) iodine may produce allergic reactions in some individuals and doubts exist regarding the advisability of long-term use of iodine for drinking water disinfection.

Ozone

Ozone (O_3) is an unstable gas which is only slightly soluble in water. It is an efficient disinfectant, but because it is unstable does not leave a residual in water unlike chlorine. For this reason it is effectively impossible to over-dose with ozone. Ozone contributes to the bleaching of colour and removal of tastes and odours.

Ozone is produced by passing dry oxygen or air through an electrical discharge. It is manufactured on-site using specialized equipment. Whilst ozone is overall the most effective disinfectant and is more effective than chlorine in inactivating cryptosporidium oocysts and viral agents, there are significant disadvantages in its use. These are primarily that ozone does not provide residual protection against recontamination during distribution and as ozone affects biological stability, it may encourage regrowth of bacteria.

However, given the concerns about the use of chlorine in many countries, the use of ozone is increasingly investigated and the lack of residual may be dealt with by employing regular booster ozonation during distribution. However, far less is known about ozonation and the effect of ozone of human health and it should be remembered that ozonation is much more expensive than chlorination.

Ultraviolet radiation

Ultraviolet (UV) radiation has been used fairly extensively for disinfection of small community water supplies.

The efficiency of UV disinfection is dependent on the intensity and wavelength of the irradiation and the exposure of the microorganisms to the radiation. UV radiation therefore decreases in efficiency as contamination (especially turbidity and some substances in solution such as iron and organic compounds) increases.

UV disinfection of water is normally achieved by passing the water through tubes lined with UV lamps. This gives efficient disinfection after a contact time of a few seconds. A typical power requirement would be within the range 10-20 W/m^3h. The lamps used disinfect using a wavelength of light around 254nm. The lamps may continue to produce blue light when they are worn out and no longer produce disinfecting irradiation.

Disinfection with UV irradiation does not give rise to tastes and odours. There is no requirement for consumable chemicals, maintenance is straight forward and there is no danger of over-dosing. UV irradiation does not leave a residual effect in the water. The equipment and consumables are expensive and water to be treated must be of consistently high clarity.

References

Anon. (1989) Disinfection of Rural and Small Community Water Supplies: a manual for design and operation. Water Research Centre. Medmenham, England.

Anon (1996) *Guidelines for Drinking Water Quality Volume III - 2nd edition*. World Health Organization. Geneva.

Tebbut, T.H.Y. (1992) Principles of Water Quality Control. 4th edition. Pergamon. Oxford.

Disinfectants and Disinfectant By-Products

Table 1: Summary of C.t values (mg/L. min) for 99% inactivation at 5°C (Clark et al, 1993)

Organism	Disinfectant			
	Free chlorine,	Pre-formed	Chlorine	Ozone, pH

	pH 6 to 7	chloramine, pH 8 to 9	dioxide, pH 6 to 7	6 to 7
E. coli	0.034-0.05	95-180	0.4-0.75	0.02
Polio virus 1	1.1-2.5	768-3740	0.2-6.7	0.1-0.2
Rotavirus	0.01-0.05	3806-6476	0.2-2.1	0.006-0.06
Bacteriophage f_2	0.08-0.18	-	-	-
G. lamblia cysts	47->150	-	-	0.5-0.6
G. muris cysts	30-630	-	7.2-18.5	1.8-2.0[a]
C. parvum	7200[b]	7200[c]	78[b]	5-10[c]

[a] **Values for 99.9% inactivation at pH 6-9.**

[b] **99% inactivation at pH 7 and 25°C.**

[c] **90% inactivation at pH 7 and 25°C.**

Presentation Plan

Section	Key points	OHP
Introduction	• all water supplies should ideally be disinfected to inactivate any	**OHP 1 Tab. 1**

	• pathogens in the water and to provide residual protection	
	• a wide range of disinfectants have been evaluated in the GDWQ	
	• principal disinfectant used world-wide is chlorine, although other	
	• disinfectants such as ozone are also used	
	• chlorinating involves addition of chlorine to water and although there are some health concerns about the use of chlorine, it is generally the disinfectant of choice	
	• other disinfectants include ozone, ultraviolet and iodine	
	• neither ozone or UV provide a residual and both iodine and ozone are carcinogenic	
	• ozone is principal alternative to chlorine, however it does not provide residual protection and affects biological stability possibly increasing the risk of re-growth of bacteria	
Selection of disinfectant - *Chlorine*	• chlorine is effective provided water is not turbid and the pH is below 8	**2,3,4,5**
	chlorine chemistry	

	• chlorine dissolves in water to form hypochlorite ion and hypochlorous acid	
	• hypochloric acid dissociates, but hypochlorous acid only partially dissociates	
	• disinfectant is undissociated hypochlorous acid; at high pH dissociated forms predominate and this reduces efficiency	
	• as tends to increase pH and hypochlorite decreases pH; it is important that the pH remains below 8	
	• chlorine reacts with ammonia to form amine compounds - nitrogen is formed during breakpoint chlorination	
	chlorine demand	
	• the total amount of chlorine in water which reacts with other compounds	
	• chlorine demand varies considerably and is the difference between amount of chlorine added to water and free residual detectable in water	
	breakpoint chlorination	
	• this is the usual method of chlorination	
	• sufficient chlorine is added to satisfy the chlorine demand, then extra chlorine added to provide a residual	

	• initial rise of breakpoint curve is due to monochloramine formation; subsequent fall is due to decomposition of monochloramine to form nitrogen	
	• once oxidation of ammonia complete, any additional chlorine leads to an increase in free residual	
	contact time	
	• disinfection with chlorine is not instantaneous	
	• different microbes take different length of time to be inactivated by chlorine, therefore need an adequate contact time; this is usually 30 minutes	
	• contact time is usually assured by passing piped water through a tank	
	• contact time is also related to pH	
	chlorine residual	
	• residual is required to provide protection against recontamination	
	• level of residual depends on water supply and local conditions	
	• there should be 0.5 mg/l free chlorine after 30 minutes contact time	
	• during outbreaks residuals should be maintained as	

	follows: 0.5 mg/l all points in the supply; 1.0 mg/l at standposts and wells; 2.0 mg/l in tanker trucks at filling	
	taste and odour problems	
	• chlorine tastes may cause rejection of water supplies by consumers	
	• bad tastes generally caused by over-dosing or presence of chlor phenols	
	• over-dosing may be through error (easy to rectify);	
	• over-dosing may be deliberate because contamination of supply (cause should identified and remedial action taken); or to ensure residual maintained at remote ends (consider booster chlorination)	
	• chlor-phenols caused by reaction with phenolic substances, often derived from algae, therefore surface water more likely to give problems than groundwater	
	• chlor-phenols have strong taste and should improve intake and source to reduce formation	
	• chlorine can also improve taste by reduction on organics and iron	
Types of chlorine	• chlorine comes in various forms	**6**
	calcium hypochlorite	

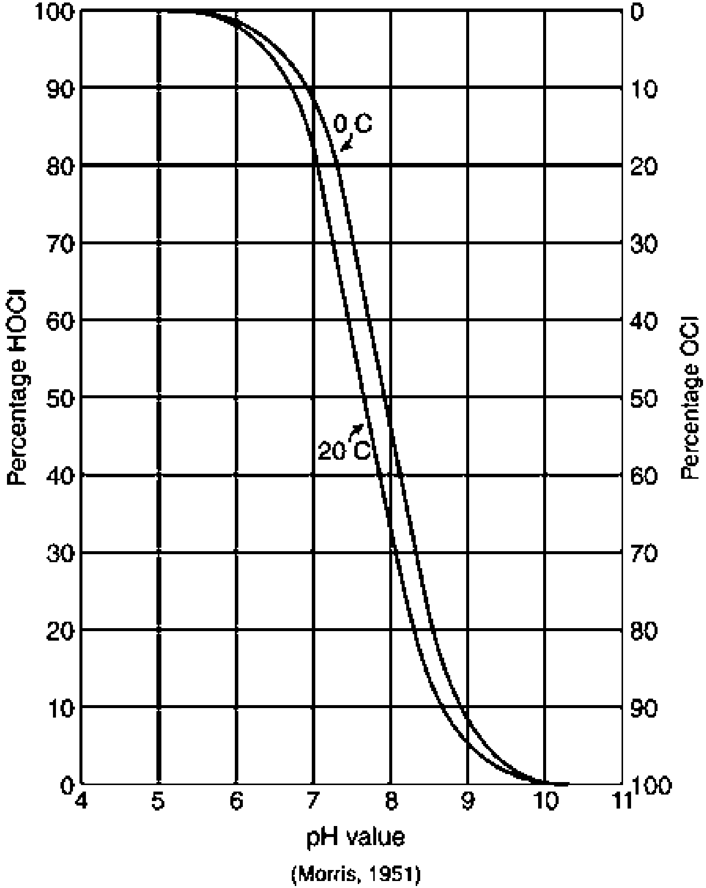
	• powder containing 30-70% available chlorine; capital costs are low and commonly used for rural and household disinfection	
	sodium hypochlorite	
	• solution containing 1-18% available chlorine, used for household disinfection	
	gaseous chlorine	
	• pure chlorine gas and most effective and efficient form of chlorine	
	• storage is important and safety measures must be in place	
Chlorination approaches	• in piped water supplies chlorine is added to ensure that any microbes in water leaving the source/treatment plant are inactivated and to provide a residual protection for the distribution system	**7,8,9,10,11**
	• under usual circumstances always maintain 0.2-.5 mg/l free chlorine residual	
	• during epidemics or risk of epidemics, residual should be 0.5 mg/l at all points in pipe and 1mg/l at standposts	
	• in point water sources, usually only disinfect during an epidemic or where risk of epidemic great	
	• residual should be 1 mg/l at all times	

	• residual should be 1 mg/l at all times	
	• chlorination may be by direct addition of HTH or by diffusion from a porous pot chlorinator	
	• continuous chlorination of point sources is expensive	
	• it is preferable to identify and remove the source of contamination that to commit to long-term continuous chlorination	
	• household chlorination may also be practised	
	• this involves addition of solutions or tablets in the home	
	• household chlorination is a short-term solution and rarely effective in the long-term	
	• should never place an over-reliance on chlorination alone for treatment of water as can get outbreaks despite adequate disinfection, treatment and source protection are vital	
	• chlorination efficiency should never be compromised by concerns regarding risks from by-products	

Disinfectants Evaluated

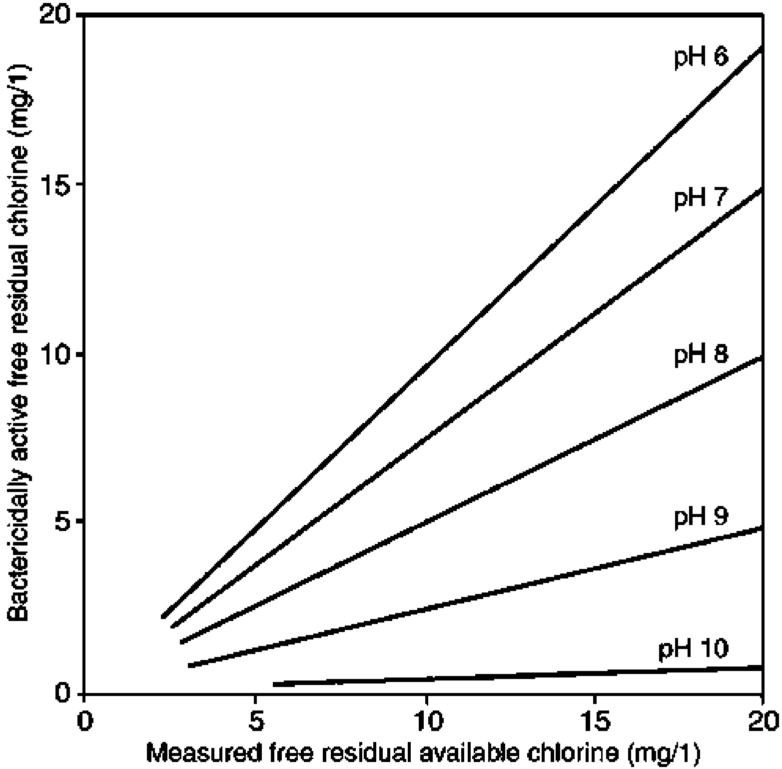
- **Chlorine**
- **Chloramine**

- **Chlorine dioxide**
- **Ozone**
- **Iodine**



Distribution of Hypochlorous Acid and Hypochlorite Ion in Water at Different

pH Values and Temperatures



Relationship between Measured Free Residual Available Chlorine ($HOCl^+$, OCl^-) and Bactericidally Active (HOCl)

Chlorine Demand

1. Make 1% chlorine solution

2. Add 6 drops of solution to 1 litre of clean water

3. Mix well & leave for 30 minutes

4. Free residual should be 1.5-2.0 mg/l, if not either add more drops or dilute with clean water until this range is reached (this is original chlorine)

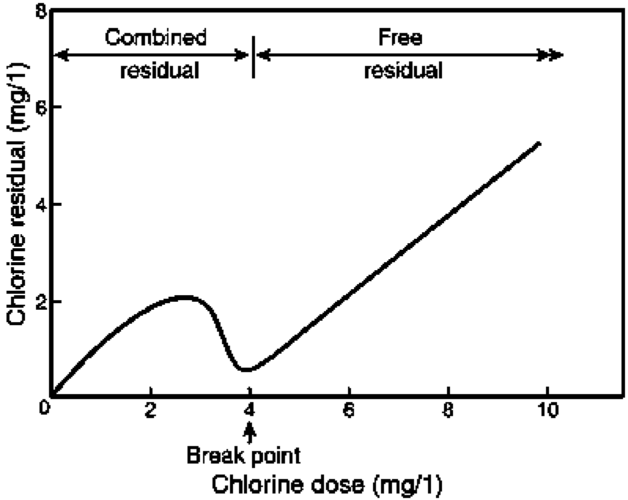
5. Measure out 500 ml into second container

6. Add 500 ml of water to be tested, mix well and leave for 30 minutes

7. Test water for free residual

8.

$$\text{Chlorine demand} = \frac{\text{Original chlorine}}{2} - \text{Residual chlorine}$$



Breakpoint Chlorination

Source: Tebbutt, 1992

Types of Chlorine Commonly Available

- **Calcium hypochlorite:**

  - powder containing 30-70% available chlorine

- **Sodium hypochlorite**

  - solution containing 1-18% available chlorine

- **Gaseous chlorine**

  - pure chlorine gas in cylinders

Chlorination in Piped Systems

- **Chlorine is added post-treatment/post source**
- **Maintain a residual at all points in network**
- **There should always be at least 0.2 mg/l free chlorine**
- **In time of cholera or other outbreak minimum is 0.5 mg/l in network and 1 mg/l at public standposts**
- **May get a reduction in residual during storage and distribution**
- **Therefore may need booster chlorination**

Chlorination of Point Sources

- **Chlorination usually only in times of outbreak**
- **Use shock chlorination and maintain free residual of 1 mg/l**
- **Chlorine may be added by direct addition:**

- HTH
- Tablets

- **Chlorine may also be added through a porous pot diffuser**

- **Can routinely chlorinate point sources if contamination always present but it is preferable to reduce contamination**

- **Point source chlorination may be difficult and expensive**

Household Chlorination

- **Only usually done in outbreaks**

- **May be from tablet dosing or through solution**

- **Must be supported by health and hygiene education and risk reduction**

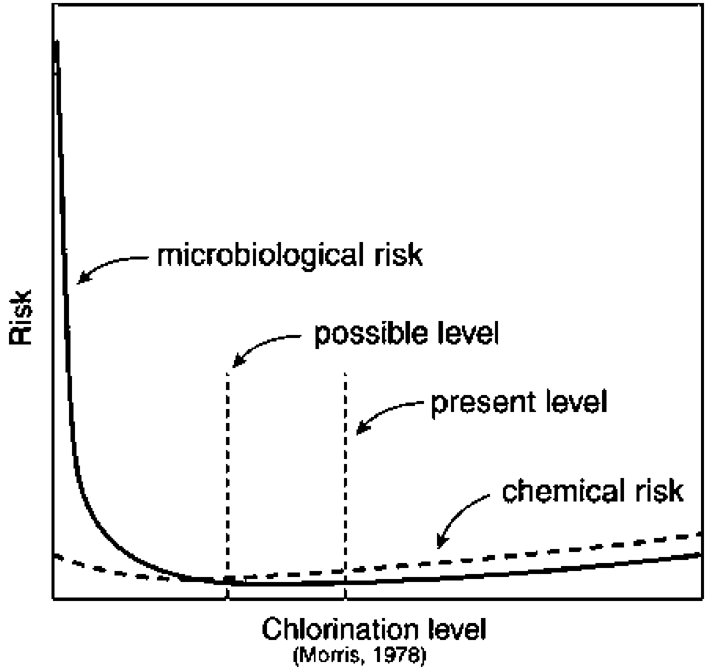
- **Household chlorination is expensive and rarely fully effective**

- **Household chlorination should be a short-term solution**

Effectiveness of Disinfection

- 1966 - New Hepatitis outbreak despite adequate chlorination

Delhi	
• 1966 - Scotland	40-50% Dysentery *S. sonnei*/viral. Due to switch failure
• 1961-1970	26,546 cases of GI due to contaminated water supply in U.S.A.
• 1971-1972	5,615 outbreaks of GI due to Rotavirus and Parvovirus in small water supplies
• Paris	Poliovirus detected in water supply despite adequate treatment
• U.K.	20% of water sources in Wales have virus contamination



Risks and Benefits of Water Chlorination

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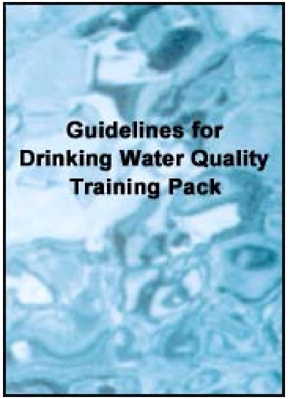
Guidelines for Drinking Water Quality - Training Pack (WHO)


Guidelines for
Drinking Water Quality
Training Pack

Water Treatment Chemicals and Construction Materials

Session Objectives

- **To describe the sources of contamination deriving from water treatment chemicals and construction materials.**

- **To demonstrate the need for product control rather than water quality analysis in controlling contamination from these sources.**

- **To describe some key contaminants deriving from the use of polyelectrolytes, PAHs and PVC.**

Introduction

Chemical contaminants in drinking-water may originate from a variety of sources, including treatment chemicals used in the production of drinking-water or from materials of construction which come into contact with water

during treatment, storage and distribution.

A listing of some chemicals used in water treatment, and drinking-water system components such as pipes, joining and sealing materials, process media and mechanical devices is given in Annex 1. Both chemicals and system components may release contaminants into the drinking-water (1, 2).

Processes used for manufacturing of water treatment chemicals may result in the presence of impurities that are of potential health concern. For example, a wide range of polyelectrolyte are used as coagulant aids in water treatment, and the presence of residues of the unreacted monomer may cause concern. Many polyelectrolytes are based on acrylamide polymers and copolymers, in both of which the acrylamide monomer is present as a trace impurity. Some polyelectrolytes may release epichlorohydrin, formaldehyde, ethylene dichloride or ammonia into the water. Chlorine used for disinfection has sometimes been found to contain carbon tetrachloride and mercury. Metals such as As, Ba, Cd, Cr, Pb, Hg, Sn, Se, and Ag may be found as impurities in a variety of water treatment chemicals.

Contaminants may originate from construction materials: metals such as copper, lead and cadmium are released from pipe material and solder; asbestos fibres from the inner walls of asbestos-cement pipes; polynuclear aromatic hydrocarbons from coal-tar-based pipe linings and coatings on storage tanks; traces of unreacted vinyl chloride monomer from PVC pipes;

organic chemicals from *in situ* polymerized and solvent-applied coating; and radionuclides from sand and granular activated carbon used as filtration media.

Ensuring the safety of water treatment chemicals and construction materials

During the development of the 1993 WHO *Guidelines for Drinking-water Quality,* the subject of potentially hazardous chemicals in drinking-water derived directly from treatment chemicals or construction materials used in water supply systems was discussed. The conclusion reached by the experts was that such chemicals are best controlled by the application of national regulations governing the quality of the products themselves rather than the quality of the water.

For this reason, the *Guidelines* have not specifically addressed contaminants derived from water treatment chemicals, construction materials, paints or coatings. Nevertheless some of the contaminants arising from these sources were evaluated because of their world-wide importance and include, for example, asbestos, vinyl chloride, acrylamide, epichlorohydrin, di(2-ethylhexyl) adipate and phthalate, and benzo[a]pyrene.

National authorities in some countries such as the Netherlands (3), the United Kingdom (4) and the United States of America (2) have issued specification and recommendations for chemicals and construction materials thus ensuring the safety of the water delivered to the consumer.

Where specifications have not been developed, contamination from these sources may adversely affect the quality of drinking-water.

National drinking-water standards (or WHO guideline values, GVs) may be used to derive limits for impurities in water treatment chemicals. Using the approach adopted by the US National Research Council and National Sanitation Foundation (NSF) (2, 5), a recommended maximum impurity content (RMIC) in the treatment chemical is calculated using the following equation:

$$RMIC(mg/kg) = \frac{NS(mg/l) \times 10^6}{MD(mg/l) \times SF}$$

were NS is the national standard (or GV), and MD the maximum dosage of the water treatment chemical. A safety factor (SF) of 10 is judged as reasonable to limit to 10% of a given NS the contribution by a given impurity in a water treatment chemical. A sample calculation of a RMIC is as follows:

Contaminant (Pb): NS = 0.02 mg/litre

Water treatment chemical: Maximum dose (MD) 500 mg/litre
Safety Factor 10

$$RMIC = \frac{0.02\,mg\,Pb/litre \times 10^6\,mg/kg}{500\,mg\,chemical/litre \times 10} = 4\,mg\,Pb/kg\,chemical$$

If a national drinking-water standard (or WHO GV) is not available, new toxicity testing and evaluation may be necessary.

The concentration of contaminants released from products used in contact with drinking-water may be initially high, but rapidly decline with continued product contact with water. The NSF has adopted an approach whereby leachate tests are conducted to determine the slope of the contaminant concentration curve. If the initial (day 1) laboratory concentration of the contaminant is less than or equal to the 90-day No-observed-adverse-effect level (NOAEL), divided by 100, and the contaminant concentration is calculated to be at or below 10% of the national standard, then no additional toxicity data may be required.

Polyelectrolytes used in water treatment

A wide range of polyelectrolytes are available and the presence of unreacted monomer may cause concern. For example acrylamide polymers and epichlorohydrin-based polymers may release in drinking-water the unreacted monomers acrylamide and epichlorohydrin. To control this type of contamination, some countries have established maximum authorised dose of polyacrylamide used as a coagulant in drinking-water treatment (range 0.25-1 mg/litre), and specified maximum acrylamide content in polyacrylamide (varying from 0.025 to 0.1%). A standard of 0.1% of monomer at a maximum dose of polyacrylamide of 0.5 mg/litre would correspond to a maximum theoretical concentration of acrylamide in water

of 0.5 mg/litre (same as WHO GV of 0.5 mg/litre for an excess lifetime cancer risk of 10^{-5}).

Because of concern about certain contaminants, Switzerland and Japan do not permit the use of polyelectrolytes, including polyacrylamide, in drinking-water treatment (6). Other countries, such as the United Kingdom, Germany and the USA, establish limits on contaminant levels and application doses, as described above, which they can monitor and enforce.

A WHO Consultant Group examined the health aspects relating to the use of polyelectrolytes in water treatment and recommended that:

(a) polyelectrolytes should be used only after careful evaluation of the toxic hazards of particular products

(b) countries wishing to use polyelectrolytes should establish a national committee to evaluate potential health hazards arising from their use

(c) limits should be specified both for the maximum applied dose of a polyelectrolyte and for its content of toxic monomer.

Polynuclear aromatic hydrocarbons (PAHs)

PAHs are present in the environment from both natural and anthropogenic

sources. A GV of 0.7 pg/litre corresponding to an excess cancer risk of 10^{-5} was recommended for benzo[a]pyrene. There were insufficient data available to derive GVs for other PAHS. The following recommendation was made in the *Guidelines* for the PAH group:

> **"Contamination of water with PAHs should not occur during water treatment or distribution. Therefore, the use of coal-tar-based and similar materials for pipe linings and coatings on storage tanks should be discontinued. It is recognised that it may be impracticable to remove coal-tar linings from existing pipes. However, research into methods of minimising the leaching of PAHs from such lining material should be carried out"**

Asbestos-cement pipes

Because of the lack of evidence for any health risk from ingested asbestos, no GV was proposed in the *Guidelines* for asbestos in drinking-water (see WHO Press Release attached in session V). However, one concern with A/C pipes is that cement is subject to deterioration on prolonged exposure to aggressive water - due either to the dissolution of lime and other soluble compounds or to chemical attack by aggressive ions such as chloride or sulphate - and this may result in structural failure of the A/C pipe. The American Water Works Association has set specifications for the type of A/C pipes to be used for different degree of aggressiveness of the water, as

reflected in the "aggressiveness" Index or the Langelier Index. Pipes made of A/C, as well as almost all other materials, may not perform satisfactorily when in contact with highly aggressive water. Adjustment of certain water quality parameters, such as pH, alkalinity and/or hardness, may thus be necessary to control cement corrosion.

PVC pipes

Contaminants that may leach from PVC material include di(2-ethylhexyl) phthalate used as a plasticizer, antioxidants such as phenols and aromatic amines, lead, cadmium and organotin compounds used as heat stabilizers, acrylic processing aids, and residual vinyl chloride monomer (VCM). Based on cancer risk assessment, a GV of 5 µg/litre has been recommended for VCM by WHO, corresponding to an excess cancer risk of 10^{-5}.

Low concentrations of VCM have been detected in drinking-water as a result of leaching from PVC pipes used in water distribution systems. A number of product standards exist which specify a quality of PVC pipes that limits the quantity of free VCM present. For example, NSF-International requires that the residual vinyl chloride monomer content of PVC material as determined in the wall of the finished product should be less than or equal to 3.2 mg/kg (2).

The European Union has set a maximum VCM level of 1 mg/kg in materials made of PVC which are intended to come into contact with food (or drinking-

water). It is further specified that VCM should not be detected in food (or drinking-water) at the limit of detection of 0.01 mg/kg (7). In order to enforce these standards, the European Union has specified the methods of analysis of VCM in PVC material (8), and in food or water (9).

The use of PVC pipes has been reviewed by a WHO Consultant Group, with special emphasis on leaching of heavy metal stabilizers and associated impurities from the pipe wall. Additives such as lead, organotin and cadmium may be used in PVC pipe production. Other potentially hazardous compounds such as mercury may occur as impurities in PVC pipe. The Group recommended that:

(a) National standards for PVC pipes should be developed setting limits on the amount of toxic stabilizers that can be extracted from the pipe.

(b) The International Organization for Standardization (ISO) should be regarded as the appropriate international body for the co-ordination of national standards and the development of uniform test procedures related to the extractability of toxic substances from PVC pipes.

(c) The use of cadmium compounds in PVC drinking-water pipe formulations is considered to be highly undesirable.

(d) Research should be carried out to determine leaching pattern of organotin stabilizers. Toxicological data on these materials are also needed in order to establish a tolerable daily intake.

(e) Toxic ingredients should be limited to the absolute minimum required for pipe production.

ISO has specified a test method for the determination of the extractability of prescribed constituents from the internal surface of plastic pipes, including PVC pipes, for the transport of water intended for human consumption. The constituents considered include monomers, initiators, emulsifiers, stabilizers, antioxidants, lubricants, polymers and copolymers for blends, UV absorbers, fillers and pigments. The method is applicable to extractable contaminants such as VCM, lead, tin, cadmium and mercury occurring as impurities in PVC materials. The purpose of the method is to verify that the extracted quantities do not exceed specified limits. However, ISO does not establish permissible limits for the quantities extracted (10).

Conclusions

Contamination of drinking-water by water treatment chemicals and construction materials may be controlled by the application of national specifications and regulations on the quality of the product. To support countries in developing control procedures for water treatment chemicals and construction materials, the Working Group on Protection and Control of

Water Quality of the Rolling Revision of the Guidelines will prepare a monograph on the techniques for testing and control of materials and chemicals, ready for publication in 2001. This will be co-ordinated by NSF International in conjunction with the International Programme on Chemical Safety (IPCS).

In addition to the evaluation of chemicals as contained in the WHO *Guidelines for Drinking-Water Quality,* the IPCS has, in its Environmental Health Criteria documents, assessed the risk of several chemicals of direct relevance to water treatment and distribution systems: phenol, chlorophenols, mercury, lead, cadmium, tin and organotin compounds, tributyltin compounds, arsenic, Polycyclic aromatic hydrocarcarbons, aluminium, etc. International risk assessment from exposure to these chemicals will assist national authorities in identifying problem areas and in establishing specifications for chemicals and materials which come into contact with drinking-water.

References

1. American Water Works Association (1990) Water quality and treatment. 4th ed. McGraw-Hill. New York.

2. National Sanitation Foundation. Standard ANSI/NSF 60-1988 Drinking-water treatment chemicals-Health effects; Standard NSF 61-1991 Drinking-water system components-Health effects. NSF International. Avenue Grand

Champ 148. 1150 Brussels, Belgium. Tel. 322-7713654; Fax 322-763-0013.

3. KIWA Ltd. Procedure to obtain a certificate of no objection on toxicological grounds. Rijswick, the Netherlands.

4. United Kingdom Committee on Chemicals and Materials. List of substances, products and processes approved under regulations 25 and 26 for use in connection with the supply of water for drinking, washing, cooking or food production purposes (December 1994). Drinking-water Inspectorate, Room B153, 43 Marsham Street, London SWIP 3PY. Facsimile: 44-71-2768405; Telephone 44-71-276-8901.

5. US National Research Council (1982) Water chemicals codex. National Academy Press, Washington, D.C.

6. Letterman, R.D. and Pero, R.W. (1990) Contaminants in polyelectrolytes used in water treatment. J. Am. water works Assoc. Vol 82, pp. 87-97.

7. Council of the European Communities Directive of 30 January 1978 on the approximation of the laws of the Member States relating to materials and articles which contain vinyl chloride monomer and are intended to come into contact with foodstuffs (78/142/EEC).

8. Commission of the European Communities Directive of 8 July 1980 laying down the Community method of analysis for the official control of the vinyl

chloride monomer level in materials and articles which are intended to come into contact with foodstuffs (80/766/EEC)

9. Commission of the European Communities Directive of 29 April 1981 laying down the Community method of analysis for the official control of vinyl chloride released by materials and articles into foodstuffs (81/432/EEC).

10. ISO (1990) International Standard 8795 Plastics pipes for the transport of water intended for human consumption - Extractability of constituents - test method. ISO, P.O.Box 56, 1211 Geneva 20, Switzerland.

ANNEX 1

I. DRINKING-WATER TREATMENT CHEMICALS

Coagulation and flocculation: acrylamide copolymers, aluminium chloride, aluminium sulphate, bentonite/montmorillonite, cationic polyacrylamide, diallyldimethyl ammonium/chloride acrylamide copolymer, ferric chloride, ferric and ferrous sulphate, kaolinite, poly (diallyldimethyl ammonium chloride), polyaluminium chloride, polyamines, starch, polyethyleneamines, resin amines, sodium aluminate.

pH adjustment: calcium carbonate, calcium hydroxide, calcium oxide, carbon dioxide, magnesium oxide, potassium hydroxide, sodium bicarbonate,

sodium bisulfate, sodium carbonate, sodium hydroxide, sulfuric acid.

Corrosion control: dipotassium orthophosphate, disodium orthophosphate, monopotassium orthophosphate, phosphoric acid, polyphosphoric acid, potassium tripolyphosphate, sodium calcium magnesium polyphosphate, sodium polyphosphate, sodium zinc polyphosphate, tetrasodium pyrophosphate, zinc orthophosphate.

Corrosion inhibitor: sodium silicate

Sequestering: ethylenediamine tetraacetic acid (EDTA), tetrasodium EDTA

Disinfection and oxidation products: anhydrous ammonia, ammonium hydroxide, calcium hypochlorite, chlorine, iodine, potassium permanganate, sodium chlorate, sodium chlorite, sodium hypochlorite.

Fluoridation: ammonium hexafluoro silicate, calcium fluoride, fluosilicic acid, magnesium silico fluoride, potassium fluoride, sodium fluoride, sodium silico fluoride.

Defluoridation: aluminium oxide, bone charcoal, tricalcium phosphate, high-magnesium lime. Algicide: copper sulphate, copper triethanolamine complexes. Softening: calcium hydroxide, calcium oxide, sodium carbonate, sodium chloride.

Taste and odour control: activated carbon, chlorine, chlorine dioxide, copper

sulphate, ozone, potassium permanganate.

Dechlorinator and antioxidant: sodium metabisulfite, sodium sulfite, sulfur dioxide.

II. DRINKING-WATER SYSTEM COMPONENTS

Pipes and related products: copper, lead, stainless steel, brass, galvanized, concrete pressure, ductile iron, PVC, chlorinated PVC, asbestos/cement.

Protective (barrier): materials: coatings, paints, linings.

Process media:

> **Adsorption media: activated alumina, granular activated carbon, powdered activated carbon.**
>
> **Filtration media: aluminium silicates (e.g. zeolites), anthracite, diatomaceous earth, gravel, sand, membranes.**
>
> **Ion exchange: ion exchange resins.**

Mechanical devices: chemical feeders, pressure gas injection systems, disinfection generators, electrical wire, pumps, valves and related fittings, water process treatment devices (e.g. mixers, reverse osmosis, screens, clarifiers, aeration equipment, etc.).

Presentation Plan

Section	Key points	OHP
Introduction	• chemical contaminants in drinking-water originate from a variety of sources.	
	• these sources include the water treatment process itself through the presence of impurities in the water treatment chemicals, drinking-water system components and contaminants originating from construction materials	
	• some of these, such as polyelectrolytes, PAHs, copper, lead and cadmium are of potential health concern	
Ensuring the safety of water treatment chemicals and construction materials	• national regulations governing the quality of the products (i.e. the construction materials and treatment chemicals rather than the quality of the water itself is used to control potentially hazardous chemicals in drinking-water)	
	• national drinking-water standards (or WHO Guidelines) may be used in a standard formula to derive limits for impurities in water treatment chemicals. Where national drinking-water standards are not available new toxicity and evaluation may be required	
	• the concentration of contaminants released from	**1**

	products used in contact with drinking-water may decline with continued product contact with water. Leachate tests determine the slope of the contamination concentration curve	
Poly-electrolytes used in water treatment	• polyelectrolytes are widely available and the presence of unreacted monomers may cause concern. These may be released by certain polymers in drinking-water	
	• as a result of the concern some countries do not permit the use of polyelectolytes in drinking-water or establish limits on contaminant levels and application doses	
	• the health aspects relating to the use of polyelectrolytes in water treatment have been identified by a WHO Consultant Group and recommendations made for their use	
Coalton linings	• may release PAHs	**3**
	• these are present in the environment from both natural and anthropogenic sources	
	• a GV for benzo[a]pyrene has been established	
	• it has been recommended in the *Guidelines* that where materials from which PAHs may leach are used, for example in pipe linings and coatings on storage tanks, alternative materials are used	
	• Guidelines recommend alternative materials where PAHs	

	may leach	
Asbestos-cement pipes	• there is no GV for asbestos in drinking-water as there is no evidence that asbestos has any adverse effect on human health when ingested with drinking-water	**4**
	• concern that cement in asbestos-cement pipes may deteriorate after prolonged exposure to 'aggressive' water	
	• specifications have been set for the types of pipes used depending on the degree of 'aggressiveness' - using the'aggressiveness' Index or Langelier Index	
PVC pipes	• a variety of contaminants may leach from PVC pipes.	**5**
	• a GV has been set by the WHO for one of these - residual vinyl chloride monomer (VCM) - of 5 mg/litre based on a cancer risk assessment	
	• low concentrations of VCM have been detected in drinking-water due to leaching from PVC pipes. The use of PVC pipes has been reviewed by a WHO Consultant Group and recommendations made for their production and use	
	• the EU has set standards for the amount of VCM in materials made of PVC which are intended to come into contact with food or drinking-water.	
	• a standard test method has been specified for the determination of the extractability of prescribed	

	constituents from the internal surface of plastic pipes used for the transport of water intended for human consumption	
Conclusions	• control of contaminants from materials and chemicals used in treatment and distribution of water are best control through product control, not water quality monitoring	
	• control of contamination of drinking-water by water treatment chemicals and construction materials may be addressed by national standards and regulations on the quality of the product	
	• WHO is actively pursuing status to provide information on approved products and quality standards to Member States	
	• the risk of several chemicals of direct relevance to water treatment and distribution systems has been assessed	
	• international risk assessment from exposure to these chemicals can assist national authorities in identifying problem areas and establishing specifications for chemicals and materials in contact with drinking-water.	

NB: Annex 1 may be given as a handout as this is not included in the

Guidelines.

Calculating Recommended Maximum Impurity Concentration (RMIC)

$$RMIC(mg/kg) = \frac{NS(mg/l) \times 10^6}{MD(mg/l) \times SF}$$

e.g. Pb NS = 0.02 mg/l; MD = 500 mg/l; SF = 10

$$RMIC = \frac{0.02\,mg\,Pb/litre \times 10^6\ mg/kg}{500\,mg\,chemical/litre \times 10}$$

Recommendations of the WHO Consultant Group on Polyelectrolytes

- **Polyelectrolyte should be used only after careful evaluation of the toxic hazards of a particular substance.**
- **Countries wishing to usepolyelectrolyteshould establish a national committee to evaluate potential health hazards arising from its use**
- **Limits should be specified both for the maximum applied dose of apolyelectrolyteand for its content of toxic monomer**

Coalton Linings

- **May release PAHs.**

- **These are present in the environment from both natural and anthropogenic sources.**

- **Guideline value for benzo[a]pyrene has been established.**

- ***Guidelines* recommend alternative materials should be used where PAHs may leach.**

Asbestos-cement Pipes

- **No guideline value for asbestos.**

- **May deteriorate after prolonged exposure to 'aggressive' water.**

- **Specifications have been set using the 'aggressiveness' Index/Langelier Index.**

PVC Pipes

- **A variety of contaminants may leach form PVC pipes.**

- **Guideline value has been set for residual vinyl chloride monomer (VCM).**

- **Low concentrations of VCM have been detected in drinking-water due to leaching from PVC pipes.**

- **Standard test methods developed for 'extractability' of prescribed constituents.**

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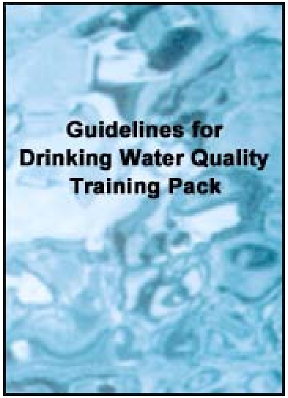


Institutional Frameworks

Session Objectives

- **To describe the key players in the water sector and describe their roles and interaction.**
- **To describe how the water supply sector should be structured and**

emphasise the need for a clear institutional framework to be established.

- **To demonstrate the need for inter-sectoral and inter-institutional collaboration at all levels.**

- **To describe the key elements of legislation required for effective monitoring linked to water supply improvement.**

Introduction

As the purpose of water supply surveillance is to promote the improvement of water supply services, it is important that the organisational arrangements intended to facilitate this pay due consideration to the vital and complementary roles of both the surveillance and the supply functions. It is also essential when establishing or reviewing the institutional arrangements of the sector with respect to surveillance and monitoring functions, that the most appropriate institution takes responsibility for surveillance functions.

Selecting Institutions and Assigning Responsibilities

There are a numbers of issues in deciding institutional homes for different functions and when doing this, it is important that the purpose of each function is clearly defined and matched against the overall remit of the

institution. The principal functions concerned are: surveillance; supply, and; resource management.

Surveillance - Ministry of Health

It is preferable that because quality surveillance is concerned with human health, responsibility is assigned to the Ministry of Health as the agency responsible for the protection of public and environmental health. This is an independent monitoring role which takes into account water quality up to the point of consumption and for all the population, regardless of the source of water. This is clearly separate from quality control monitoring of water production and supply exercised by water suppliers within their area of supply. The separation of surveillance and supply functions is desirable to prevent any actual or perceived conflicts of interest from occurring.

However, given changing political structures and responsibilities for water supply, it may often not be practical to make the Ministry of Health responsible for field data collection as they may lack the necessary staff, skills and resources. The Ministry should, however, always maintain a national profile in water quality surveillance as a key preventative health activity.

Operational surveillance activities may be undertaken by local government environmental health bodies, with the Ministry of Health playing a co-ordinating and facilitating role. In many ways, this is the preferred scenario

if local government does not have responsibility for water supply. Where local government also assumes responsibility for water supply, there may potentially be a conflict of interest. In such circumstances they may be financial and political objections to a centralised system of surveillance operated by the Ministry of Health. In these circumstances, there must be clear separation of responsibility for supply and surveillance up to the most senior levels, or an alternative body established taking responsibility either for supply (which is usually the favoured course) or surveillance.

Where a government department takes overall responsibility for development of water supplies, there may be some scope for them to undertake routine monitoring if the supplies are operated by another entity, although clearly it is questionable if they can be truly independent. Alternative bodies to the Ministry of Health can take responsibility for surveillance - for instance the environment sector - but as these are not health bodies, the Ministry of Health must retain a strong interest in the operation of surveillance networks and the data produced.

Quality control - Water supply agency

The water supply usually has a responsibility to ensure that the water supplied up to the connection with a house main or connection with a standpost riser or point of exit from a point water supply is of a wholesome nature and is fit for consumption. Usually this is measured against national standards and norms of water supply. This is separate function to

surveillance as it is not concerned with the quality of water as *consumed* but of the water as *supplied.*

The meeting of national standards is usually a legal requirement which is enforced through surveillance. The frequency of quality control sampling, the techniques used and methods of quality control and reporting are generally standardise where piped water supplies operated by a supply agency serve a population of consumers. Where community based water supplies are used, whether point or piped, the supplier cannot usually reasonably be to undertake routine quality control monitoring and under these circumstances it is common that either only surveillance activities are undertaken or that the agency responsible for the development of community supplies to carry out quality control monitoring in addition to the surveillance function undertaken by environmental health staff.

Water resources - Resource management agency

A further complication to the institutional arrangements is when an independent water resource management/natural water quality monitoring body is established. This is an appropriate system where sufficient resources exist to fund the functioning of two regulatory bodies. The roles and responsibilities of natural and drinking-water regulatory bodies are very different and different types of qualification and experience are desirable in each. However, where resources are limited, it is sometimes found that the same body takes responsibility for both natural and drinking-water quality.

This is not an unreasonable approach to be adopted, provided that a balance can be struck between the needs of both can be maintained. This is not necessarily easy, particularly where financial resources are scarce and has proven to be difficult to operate in many countries, usually to the detriment to drinking-water quality surveillance and protection.

When both forms of monitoring are placed within the same organisation there can be conflicts in approach and priority. For instance, the drinking-water quality surveillance arm, whilst recognising the need for protection of water quality in sources used for drinking, may not be sympathetic for the need to maintain water quality in water bodies exploited for other uses such as industry. Additionally, the drinking-water surveillance arm will place a higher priority on the quality of water in the supply system (i.e. during treatment and afterwards) than on raw water quality. On the other hand of course, the natural water quality monitoring arm will place great emphasis on the need to protect natural water quality and may attach little importance to post-treatment contamination on small scales. There is also a problem in that drinking-water quality standards are inherently stricter than most environmental standards and require a greater frequency of analysis. Again this may lead to difficulties in prioritising investment of limited resources.

Sector Structures

There are a number of different ways the sector can be structured and it is preferable to simplify this rather than create too many institutions with

similar responsibilities. This not only makes enforcement difficult, it is confusing to the public who become unsure as to whom they should approach for action in the event of a problem.

Despite the many different institutional models that are available world-wide, the mostly commonly applied (and probably most simple model) is one where there are three principal institutions:

1. **Water supply and sanitation agency(s);**
2. **Drinking-water supply surveillance body;**
3. **Water resource management agency - this may include pollution monitoring inspectorates.**

The relationships between surveillance body, supplier and water resource management body should be clearly defined from the outset and in particular the legal framework within which they operate should be simple, clear and effective. What is of greatest importance is to define the limit of responsibility of each of the two regulatory bodies.

In general, the water supply surveillance body takes responsibility for the water once it enters the water supply system (the intake) up to the point of consumption (the tap). The water resource management agency takes responsibility for the development, management and protection of natural water and therefore their responsibility is for source waters up to the point of abstraction for use and from the point of discharge of return flows of

wastewater. The water supply agency is obviously responsible for the integrity of it's infrastructure and effectiveness of any source protection or treatment applied to the water. There responsibility is therefore to produce a product of acceptable quality and have a responsibility from the point of abstraction to the point of connection with a house main or standpost riser or to the point of collection in point water supplies. This situation is complicated where the vending of water supplies at communal water points is licensed to water vendors, as they also have a responsibility to maintain the integrity of the riser pipe and fittings on the standpost and for timely reporting of faults to the bulk supplier.

Surveillance agency

The surveillance agency should preferably be established by national legislation and have representation at policy-making and all executive levels (such as central, departmental, regional, local or district levels).

The responsibilities of the surveillance agency should encompass monitoring of the fulfilment of water supply service standards by the water suppliers, approval of drinking-water sources (subject to specific treatment requirements where appropriate); and surveying the provision of drinking-water to the population as a whole.

Surveillance is concerned with *all* types of water used for domestic purposes by the population *as a whole*. This is a fundamental distinction to the role of

the supplier who should be responsible only for the quality of the service they provide in the area in which they operate. The area of responsibility of the surveillance agency should ideally encompass all sources of water intended for human consumption. In practice this is often difficult to achieve as many households or small communities may have individual supplies (whether a single household well or spring or a small piped distribution system). As the number of such systems may be very high, the surveillance of all such supplies may be a costly and difficult-to-achieve goal. Priority should therefore be given to:

- **systems supplying water to larger centres of population;**
- **systems suspected of being a risk to human health; and**
- **to be a representative sample of other types of supply in order to identify the most common shortcomings of these.**

Water supplier

The above does not exclude water supply and construction agencies from involvement in surveillance and in fact it is vital that they are involved.

While it is the responsibility of the surveillance agency to generate and summarise surveillance data and to promote improvements, it is the supply agency who will carry out many of the actions for improvement.

Supply agencies also have an obligation to monitor and control the quality of the product they supply, in common with the suppliers of any other types of product. This function is often referred to as *quality control* in order to distinguish it from the health-related *surveillance* function performed by the surveillance body.

In many countries arrangements to share water quality data exist between surveillance and supply agencies. In some these arrangements are informal and instigated at local level. In other cases they are formalised and the surveillance agency accepts data generated by the supplier in place of some of the data it would otherwise generate itself, provided the laboratories of the supply agency are open to inspection and the surveillance agency maintains a realistic minimum proportion of analyses for overseeing purposes.

Water resource management agency

The water resource management agency monitors natural water quality and wastewater discharges. They will also licence abstraction, monitor industrial discharges etc., but their key role within water supply is to protect source water quality so that it remains at a quality consistent with use in drinking-water supplies and for ensuring that return flows do not cause deterioration in natural water quality. They should have the power to prosecute water and sewerage agencies for failure to meet wastewater quality standards and to monitor water abstractions to ensure compliance with agreed limits.

The water resource management agency may also monitor natural water quality changes due to leakage from water supply pipes and sewers and have the power to force suppliers to carry out remedial action to improve performance in order to protect natural water quality. This is particularly important in relation to groundwaters in urban areas, where excessive leakage from sewers or water supply pipes will affect natural groundwater quality.

To a certain extent this overlaps with responsibilities undertaken by the water supply surveillance agency as they too will monitor leakage, albeit from a health related stance. This provides a good illustration of the need for strong inter-institutional links and for clear definition of responsibility. In principle, both the water resource management and the surveillance body could take enforcement action against the water and sewerage supplier, or bring a joint action. In practice, this frequently does not occur as, for instance, the surveillance body may not be interested in pursuing an action where they see no direct harm to the water supply.

Inter-Agency Collaboration

What is clear from the above is that there needs to be strong inter-agency collaboration if the water sector is to function effectively and efficiently (See Figure 1). There are many potentially overlapping roles and conflicting interests. Many of the problems that arise within the water sector are caused by a lack of dialogue and a certain element of shirking responsibility which

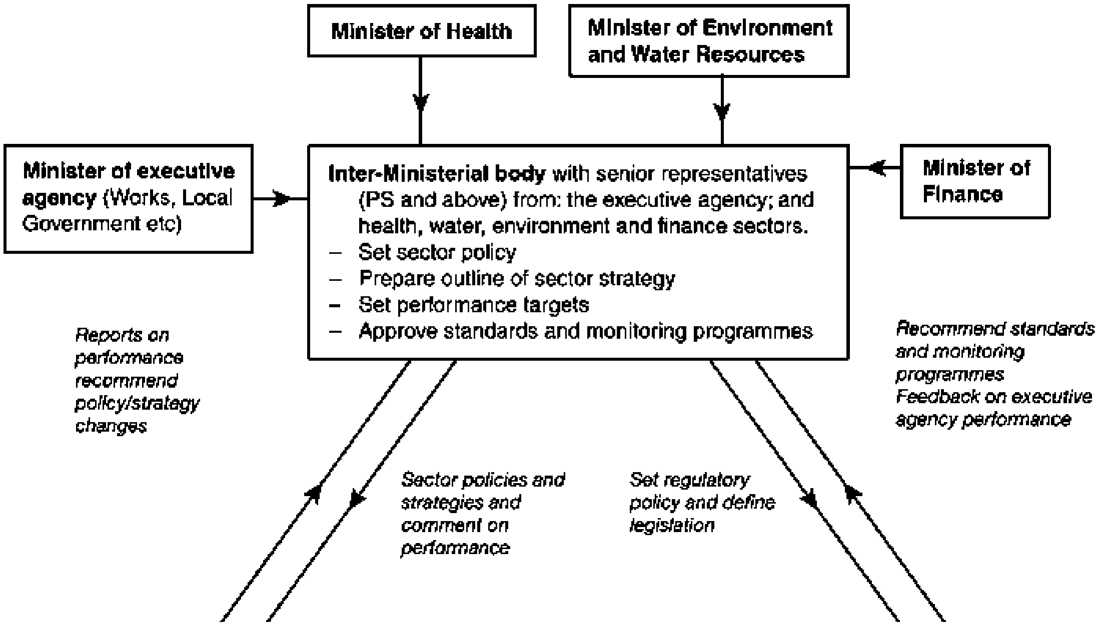
can only be resolved through adequate dialogue.

To provide an example, imagine a situation where the water resource management agency grants a discharge consent to a chemical company several kilometres upstream from a water supply intake. The plant is discharging halogenated organic material. Neither the water supply agency or the surveillance body are consulted and the plant starts to discharge. Some while later, the surveillance body starts to detect raised levels of halogenated organics in the water supply and therefore initiates action against the water supplier.

The water supplier, by identifying the elevated level of pollutants in the source water could ask the water resource management agency to prosecute the polluter in order to cover the costs of installing expensive additional treatment processes. As the polluter has a discharge consent and meeting the conditions of that consent they can argue that they are not liable for this. This leads to a situation where no-one will take responsibility for improving the quality of the water supplied to the consumers. In this situation the water supplier and surveillance agency could make a case against the water resource management body for negligence of duty.

The scenario outlined above may seem unlikely, but similar incidents have occurred worldwide. If a process of dialogue is maintained between all parties at all levels, these incidents should not occur as there will be thorough evaluation of impacts from all points of view. Taking the example

above, the water resource management body would be expected to undertake an environmental impact assessment of the discharge. However, this may or may not include influences on the water supply itself and may not look at human health impacts of ingestion of contaminated water. If a combined assessment had been undertaken, including looking at treatment implications for the water supplier and the health impacts, a more clearly defined picture could be built up about the discharge. This would be likely to change the terms of the consent and the cost of the consent to the industry.



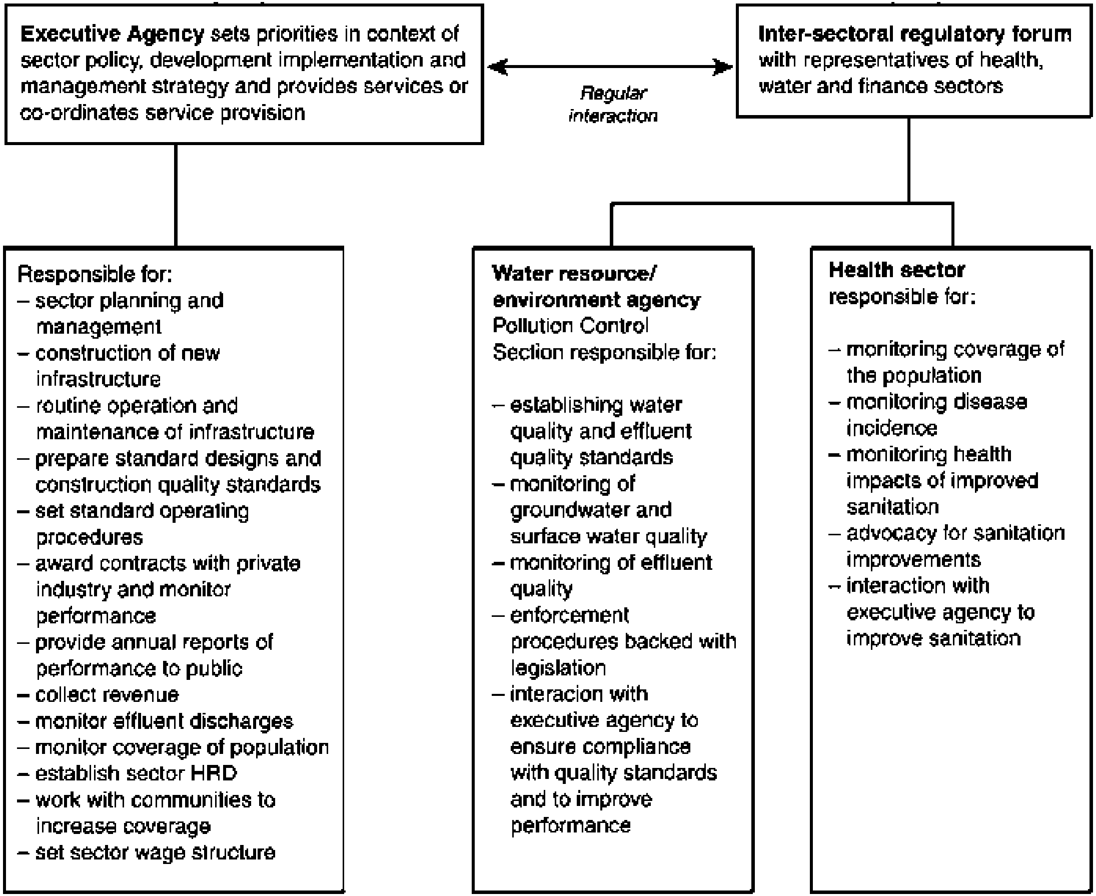


Figure 1: Institutional framework for the water supply and sanitation sector.

Howard G., 1996

Laws, Regulations and Standards

Effective water supply monitoring programmes require the support of appropriate legislation, regulations, standards and codes of practice. Important aspects which should be considered in supportive legislation include:

- **functions, authority and responsibility of the water supply agency**
- **functions, authority and responsibility of the surveillance agency**
- **functions, authority and responsibility of the water resource management agency**
- **codes of practice regarding the notification of changes in source water quality to both supply and surveillance agencies by the resource management agency**
- **codes of practice regarding the construction, organisation and maintenance of facilities by water suppliers**
- **codes of practice regarding the construction of domestic facilities**
- **water quality standards and provisions for their updating**

- **procedures for authorisation of sources as suitable for drinking-water supply**

- **minimum treatment requirements according to source water quality**

- **requirements of disinfection and minimum residual disinfectant concentrations to be maintained throughout distribution**

- **procedures for approval of sampling and analytical methods for use in water quality laboratories and analytical quality control requirements of such laboratories**

- **requirements of water suppliers to undertake a defined minimum sampling programme**

- **guidelines on procedures to follow, including notifying and providing advice to the public if contamination of drinking-water occurs**

- **provision of legal recourse to the public and surveillance agency to initiate legal action to ensure adequate water supply service quality**

- **definition of 'adequate water supply service quality' with regard to parameters such as 'continuity'**

- **code of practice to ensure that discharge consents in a catchment**

are only granted after full consultation with supply and surveillance bodies.

However, it is important to recognise the limitations in a purely legislatively driven approach to water quality monitoring as a means of improving poor water supplies in low-resource situations. The development of partnership approaches and the encouragement of all stakeholders in the sector playing an active role in monitoring water supplies and identifying improvements may be more effective where resources are limited.

Conclusion

The development and optimisation of the institutional framework in the water sector is essential for effective, output driven water quality monitoring. Unless the roles and responsibilities of each player are established and recognised, then the generation of monitoring data and information may not lead to the desired improvement in water supplies.

Water quality is a multi-agency issue which requires effective collaboration from all the key stakeholders. Whilst, legislation plays a role in achieving this, it is important to note that partnerships between regulators, suppliers and consumers may be more effective in promoting good water quality, particularly where resources are limited.

References

Bartram, J and Ballance, R. (1996) *Water Quality Monitoring*, Chapman and Hall, London.

Howard, G. (1996) *Urbanisation, Sanitation and Environmental Health,* Commonwealth Secretariat, London.

Presentation Plan

Section	**Key points**	**OHP**
Introduction	• Surveillance is intended to promote water supply improvements	**1**
	• Institutional arrangements are therefore vital	
	• Surveillance and supply functions are distinct but complementary	
Selecting Institutions and Assigning Responsibilities	• Match the requirements of each function to the remit of the institution	**2**
	• Ministry of Health is preferred for surveillance as this is a health-related activity	
	• Separation of supply and control functions is important to reduce the risk of conflicts of interest arising	
	• There are risks in over-centralising surveillance through	

	• There are risks in over-centralising surveillance through the Ministry of Health as this may replicate local capacities and increase costs	
	• Surveillance often best delegated to environmental or public health departments in local authorities	
	• Where Government takes responsibility for water supply, the same body may undertake surveillance, provided there is adequate separation between functions up to the most senior level	
	• An alternative approach is for water suppliers to generate monitoring data that is routinely submitted to the surveillance body	
	• A water resource management body may sometimes undertake surveillance	
	• Advantage of this approach is that it minimises replication of equipment and facilities	
	• However, the remit of surveillance and other activities must be clearly defined and surveillance given adequate priority	
Sector Structures	• These should be simple to optimise performance	**3,4**
	• Most common model is based on 3 agencies: surveillance agency; water supplier; resource management agency	

	• Clearly define relationships and legal framework from the outset	
	• Suppliers responsibility is from intake to connection of supply main to house main and house connection to mains sewers to the point of effluent discharge	
	• Surveillance agency responsibility runs from source to the point of consumption	
	• Resource management responsibility is natural waters and wastewater discharges	
	• Surveillance agency should be established by legislation and be represented at policy and all executive levels	
	• Should monitor fulfilment of all water supply service standards	
	• Should be a national body	
	• When establishing surveillance programmes must prioritise activities	
	• Resource management agency role is to monitor and control natural water quality and effluent quality	
	• Prosecutes polluters (including water and sewerage providers) when fail to meet standards	
	• Monitor all impacts on water resources and take	

	appropriate actions	
Inter-agency collaboration	• Inter-agency collaboration must be string for sector to function effectively and efficiently	**5**
	• Dialogue reduces litigation and is more cost-effective	
	• Give an examples of potential problems resulting from poor collaboration	
Laws, Regulations and Standards	• Laws, regulations and standards should cover all aspects of the water sector	
	• Refer to legislative frameworks session	

Institutional Framework

1. Surveillance and control monitoring are designed to promote improvement

2. Institutional arrangements are vital

3. Responsibilities must be clear

4. Institutional responsibilities should be compatible with wider concerns

5. Surveillance, supply and resource management are complimentary

Key Sector Institutions

1. **Water and sewerage service provider(s)**

2. **Drinking water surveillance body**

3. **Water resource management agency - may include pollution inspectorates**

Institutional Responsibilities

Surveillance agency:

- **Monitor water supply quality to the population as a whole**
- **Authority to sample from anywhere in all water supplies**
- **Authority to enforce compliance**
- **Should establish a sanitary code**
- **Must keep the public informed**

Supplier:

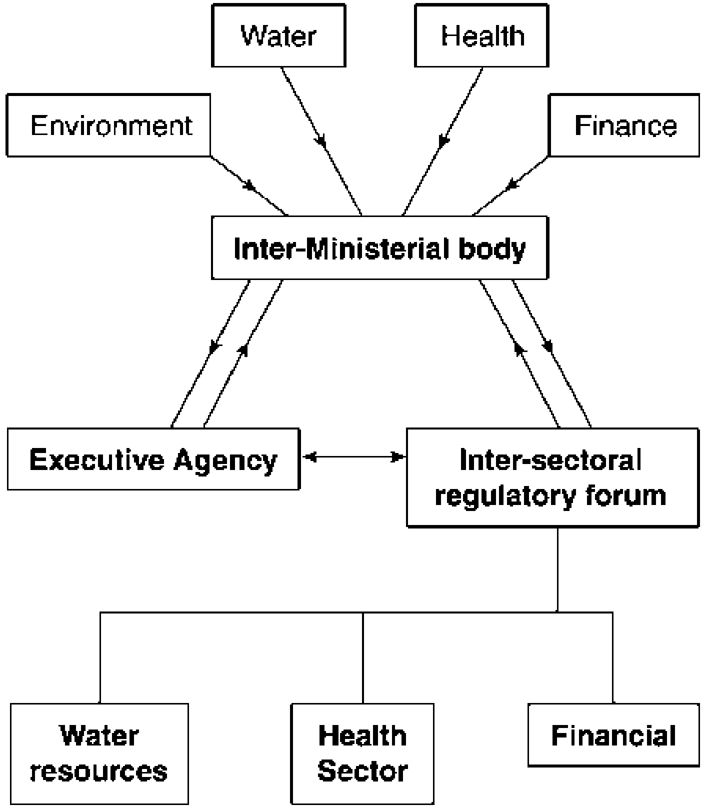
- **Supply water meeting all national standards to consumers**
- **Exercise quality control and allow access to data**

Resource Management Agency:

- **Monitor natural water quality and pollution - enforce standards**
- **Protect and manage water resources**

Limit of Institutional Responsibility

- **Surveillance agency: Source to point of consumption**
- **Water suppliers: Source to house connection/point of collection**
- **Resource management agency: All water resources**



Institutional Framework for the Water Sector