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.

Monitoring and Assessment of Microbiological Quality

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.

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Monitoring and Assessment of Microbiological Quality

Presentation Plan

Section	Key points	OHP
Introduction	• routine monitoring and assessment of microbiological quality is the key priority for suppliers and surveillance agencies • 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	**1,2,3**
Planning monitoring and assessment	• monitoring and assessment only effective when well 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	**4,5,6**

Section	Key points	OHP
Analytical ranges	• this has led to the concept of the critical parameters by WHO • 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	**7,8**
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 • 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	**9,10, 11**
Sampling frequencies	• minimum sampling frequencies have been defined by WHO for piped and point water sources • 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	**12, 13,**

Section	Key points	OHP
Linking monitoring to improvement	• water quality monitoring should be linked to improvement in water supply by identifying remedial and preventative actions • 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	**14**

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

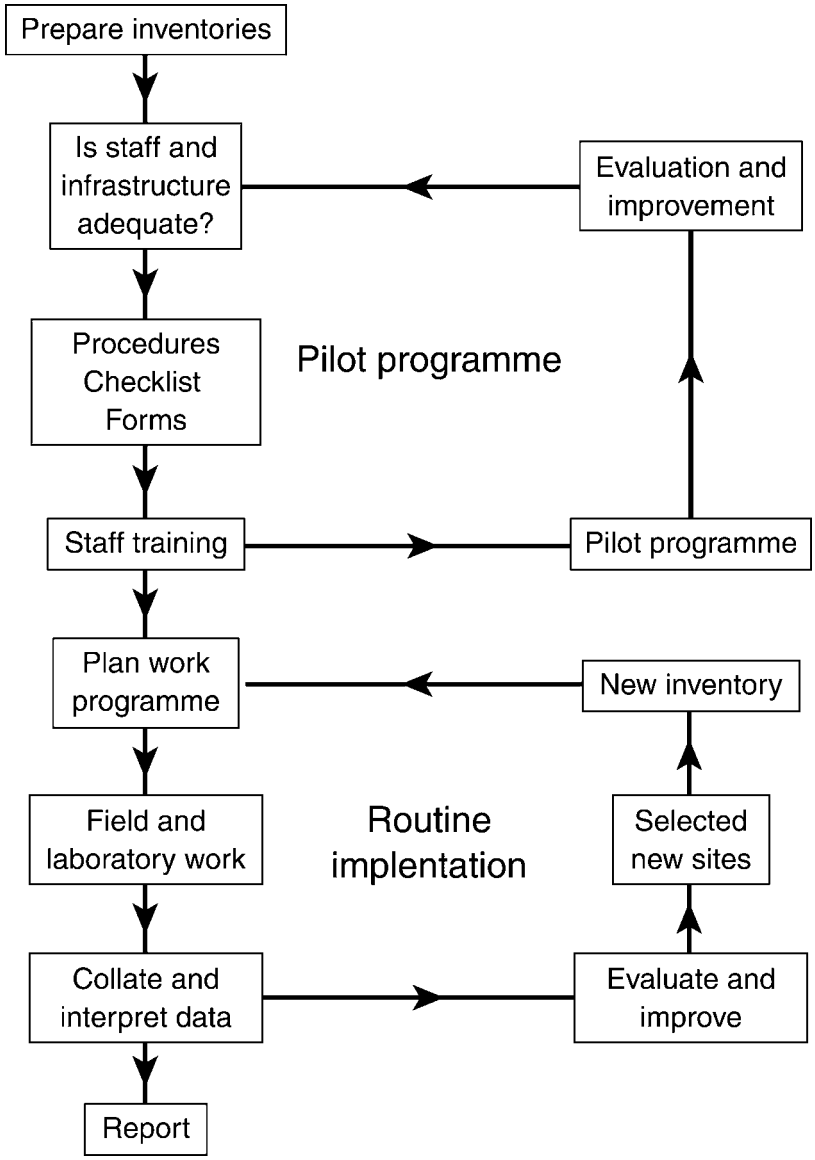
Ensuring Microbiological Quality

- 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	0/100ml
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

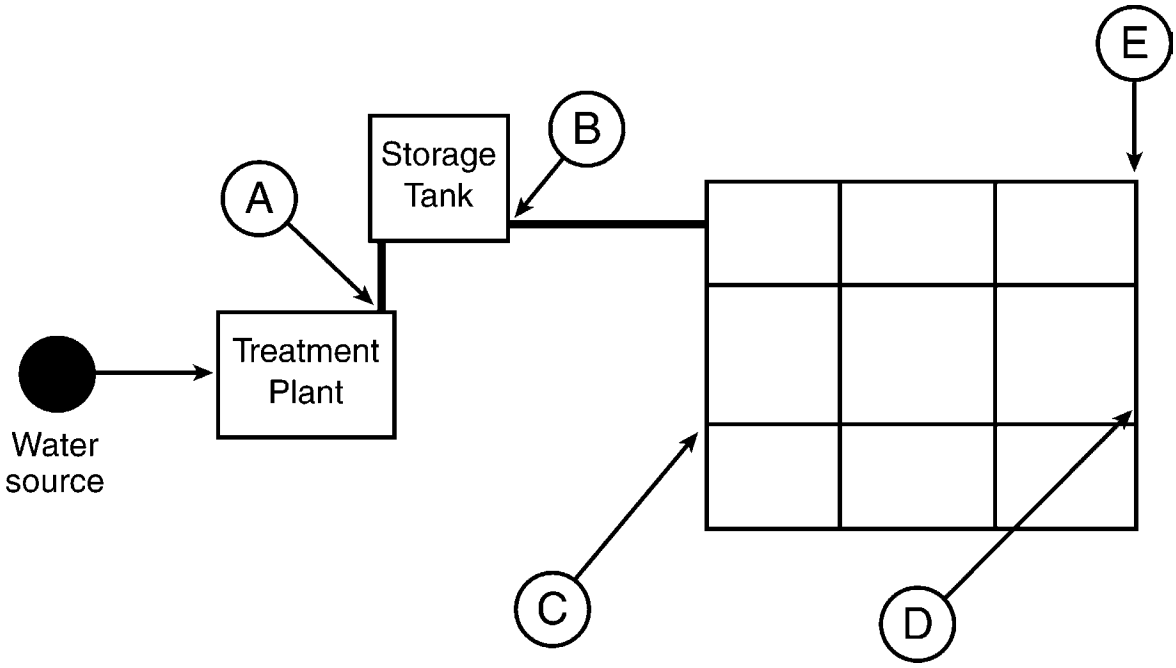
Design of Surveillance Networks

- 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

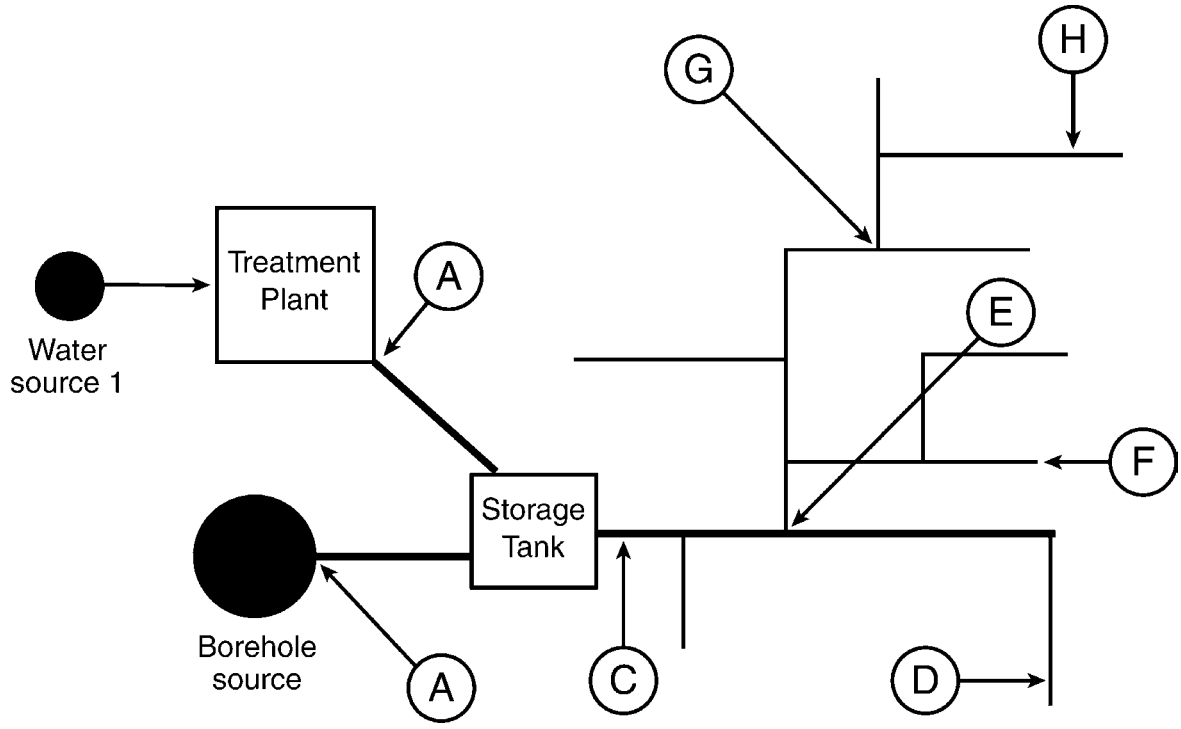
- Use ‘zoning’ for large systems with several sources.

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

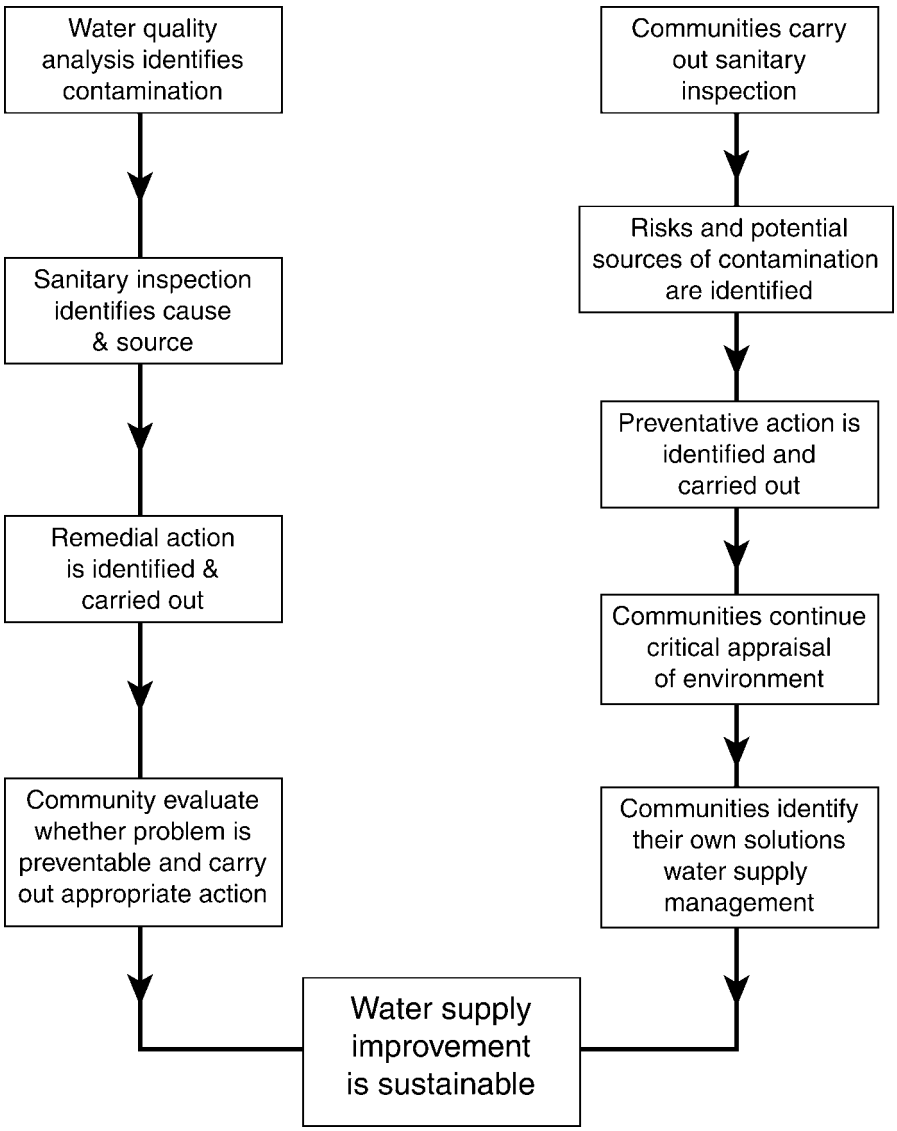
Classification of Sample Sites

- **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