Chapter 9 Overview of monitoring

9.1 Introduction

The Framework approach to drinking water quality management outlined in Chapters 2–4 is based on a preventive strategy which focuses attention on total system management. A key aspect of this approach is monitoring programs to verify that the barriers and the system as a whole are working effectively to deliver safe water. Monitoring includes:

- ***Operational monitoring***, which is used to check that the processes and equipment that have been put in place to protect and enhance water quality are working properly. The data are used, if necessary, as a trigger for immediate short-term corrective action to improve water quality, but they are generally not used for assessing conformance with the *Australian Drinking Water Guidelines* (ADWG) or compliance with agreed levels of service. Further information on operational monitoring is provided in Section 3.4.2.
- ***Drinking water quality monitoring***, which is a wide-ranging verification of the quality of water in the distribution system and as supplied to the consumer. The data are used for assessing conformance with the ADWG or compliance with agreed levels of service and/or regulations and, if necessary, as a trigger for corrective action to improve water quality. Background information on drinking water quality monitoring is provided in Section 3.5.1.
- ***Monitoring of consumer satisfaction***, which is an assessment of consumer comments and complaints. It can provide valuable information on potential problems that may not have been identified by performance monitoring of the water supply system. Background information on monitoring of consumer satisfaction is provided in Section 3.5.2.
- ***Investigative and research monitoring***, which includes strategic programs designed to increase understanding of a water supply system, to identify and characterise potential hazards, and to fill gaps in knowledge. It includes baseline and emergency response monitoring. Background information on investigative and research monitoring is provided in Section 3.9.1.

The requirements for each of these types of monitoring differ in terms of water quality characteristics to be measured, sampling location and frequency of sampling. For example, operational monitoring will be frequent and undertaken immediately after water has been treated. Monitoring for investigative and research purposes would be less frequent. Further information on monitoring, including QA/QC and occupational health and safety considerations is also available in the NWQMS *Australian Guidelines for Water Quality Monitoring and Reporting* (2000).

9.2 Developing a monitoring program

Monitoring programs should be developed, detailing the strategies and procedures to follow for monitoring the various aspects of the water supply system. The monitoring plans should be designed by personnel experienced in the assessment of water quality, and should be fully documented. The plans should include the following information:

- parameters to be monitored
- sampling location and frequency
- sampling methods and equipment
- schedules for sampling
- methods for quality assurance and validation of sampling results
- requirements for checking and interpreting results
- responsibilities and necessary qualifications of staff
- requirements for documentation and management of records, including how monitoring results will be recorded and stored
- requirements for reporting and communication of results.

Programs should be designed to cover both random and regular variations in water quality, and to give information representative of the quality of water supplied to consumers. For example, water quality is usually tested by taking samples of water from points in the system and analysing them either in an analytical laboratory or on site. It is important that the results of these tests are representative of all the water throughout the system, including the water that is there between sampling events. Also, sampling must be frequent enough to enable the program to provide meaningful information. Box 3.4 (see Section 3.5.1) details what is needed to ensure that monitoring is representative, reliable and fully validated.

Monitoring programs and the key characteristics to be monitored should be reviewed periodically, and altered where necessary.

9.3 Surrogates and indicators

Some of the more common water quality characteristics can sometimes serve as surrogates or indicators for characteristics that are less common or for which testing is more difficult and expensive. For example, conductivity is a widely used surrogate for total dissolved solids (TDS). Similarly, trihalomethanes (THMs), which are the most common disinfection byproducts and occur in the highest concentrations, serve effectively as a surrogate for a range of related byproducts. Table 9.1 shows a number of indicators, both physical and microbial, that can be incorporated as part of the risk management approach outlined in Chapters 2–4.

Table 9.1 *Examples of water quality indicators*

Hazard or hazardous events	Indicator
Faecal contamination of source water	• Sanitary survey
	• Turbidity
	• *Escherichia coli* (or thermotolerant coliforms)
Treatment failure	• Turbidity/particle size distribution
	• Free chlorine
	• Total coliforms
	• Heterotrophic plate count (HPC)
	• *Escherichia coli* (or thermotolerant coliforms)
Faecal contamination from ingress	• Ammonia
	• Enterococci
	• *Escherichia coli* (or thermotolerant coliforms)
	• Sudden change in dissolved oxygen, free chlorine or pressure
Water stagnation	• Loss of disinfectant residual
	• Dissolved oxygen
	• Heterotrophic plate count (HPC)
	• Total coliforms
Disinfection byproducts	• Trihalomethanes

Baseline and trend assessment monitoring should be used to establish and affirm such associations. Where surrogate monitoring is possible, control of the surrogate to low levels increases the assurance that objectionable characteristics associated with it are either absent or reduced.

9.4 Collection and analysis of samples

If the data collected are to be meaningful, it is vital that samples are collected from appropriate locations (as discussed above), by trained personnel working to a predetermined plan, and that procedures employed in the collection, preservation and transport of samples to the laboratory are chosen with regard to the characteristic being measured.

It is important that the results obtained in analyses are valid. In some cases, different methods of analysis can give different results. For each of the characteristics listed in the ADWG, a suggested method of analysis is given that will ensure consistent results are obtained. Other methods may be used, but they must be fully documented and validated, preferably through comprehensive inter-laboratory comparison programs, and must give results consistent with other standard methods being used.

Specific details regarding preservation of samples are given in the procedures in Part IV (Information Sheet 2.1 *Sampling procedures).*

Field testing

It is possible to acquire, at reasonable cost, robust basic chemical test kits for the common physical and chemical characteristics, including pH, colour, iron, manganese, turbidity, chlorine and fluoride. These test procedures are well within the capabilities of well-trained treatment plant operators. The test results will not have the standing of those produced by National Association of Testing Authorities (NATA) registered laboratories, but they do permit regular and frequent monitoring, and what the tests sometimes lack in precision and reliability is more than compensated for by the increased frequency of monitoring. Furthermore, such kits enable many tests to be performed in the field, thus avoiding the need to preserve and transport samples to a laboratory. Their use is encouraged, but should be regarded as complementary to, not a replacement for, more reliable laboratory tests.

Some tests, including those for dissolved oxygen, pH, temperature, free chlorine and combined chlorine, need to be done in the field. It is essential that those doing field testing are appropriately trained, and that a quality assurance program be in place to monitor testing performance.

Sampling procedures

Procedures for sampling physical and chemical characteristics, heavy metals, organic chemicals, pesticides and microbial characteristics are provided in Information Sheet 2.1 *Sampling information – handling requirements and preservation.*

9.5 Operational monitoring

9.5.1 CHARACTERISTICS TO MONITOR AND LOCATION

The characteristics selected as parameters for operational monitoring should:

- reflect the operational effectiveness of each process or activity
- provide an timely indication of performance
- be able to be readily measured and rapidly responded to.

To comply with these requirements, surrogates are often used as operational parameters, as described in Section 9.3. Examples of some of the parameters commonly used for operational monitoring are given in Table 9.2.

Table 9.2 *Examples of operational parameters*

	Treatment step/process					
Operational parameter	**Raw water**	**Coagulation**	**Sedimentation**	**Filtration**	**Disinfection**	**Distribution system**
pH		✓	✓		✓	✓
Turbidity (or particle count)	✓	✓	✓	✓	✓	✓
Temperature	✓		✓		✓	✓
Dissolved oxygen	✓					
Stream or river flow	✓					
Rainfall	✓					
E. coli (or thermotolerant coliforms)	✓				✓	✓
Total coliforms					✓	✓
Heterotrophic plate count (HPC)					✓	✓
Colour	✓					
Conductivity (total dissolved solids)	✓					
Alkalinity	✓	✓	✓			
Organic carbon	✓		✓			
Algae, algal toxins and metabolites	✓					✓
Chemical dosage		✓			✓	
Flow rate		✓	✓	✓	✓	
Net charge		✓				
Streaming current value		✓				
Headloss				✓		
C.*t*					✓	
Disinfectant residual					✓	✓
Disinfection byproducts					✓	✓
Hydraulic pressure						✓

C.*t* = a measure of disinfection concentration (C) and contact time (*t*)

9.5.2 FREQUENCY OF MONITORING

Operational parameters should be monitored often enough to reveal any failures in a timely fashion. Online and continuous monitoring should be used wherever possible, particularly at critical control points (see Section 3.3.2). For example, where filtration is used, continuous monitoring of turbidity (or particle count) from each individual filter and from the product water outlet of the plant are important to ensure that treatment is effective. For operational parameters that are deemed less critical or that are more stable, 'grab' samples may be sufficient.

9.6 Drinking water quality monitoring

9.6.1 MONITORING OF KEY CHARACTERISTICS

As it is neither physically nor economically feasible to test on an ongoing basis for all substances or organisms that may be present in water, monitoring effort and resources should be directed at significant or 'key' characteristics – that is, those characteristics that require frequent monitoring. Each water supply system will have its own key characteristics, and these need to be identified by evaluating the significance of all water quality characteristics within a water supply system. Key characteristics will also be different for each of the main component parts of the system, that is:

- raw water entering the supply system from a catchment, storage or bore field
- treated water leaving the plant
- distributed water in the reticulation system in major mains, service reservoir storages and reticulation mains
- water supplied to the consumer.

An initial survey to determine key characteristics should include chemicals used or present in the catchment, together with sufficient data to establish likely variations in concentration. Key characteristics should be measured as close to the water or contamination source as possible (as this is simpler to do and hence a more efficient use of resources), provided that the concentration does not change further down the system.

Key characteristics related to health will include:

- microbial indicator organisms
- any chemicals used in treatment processes and any byproducts that may result from their use
- any characteristic that can be reasonably expected to exceed the guideline value, even if only occasionally
- potential contaminants identified in catchment surveys
- pollutants likely to be present but not listed in the ADWG.

Key characteristics that are not related to health include characteristics with significant aesthetic impacts.

9.6.2 MONITORING ZONES

Large, complex reticulation systems should be divided into discrete zones or basins for the purposes of monitoring and reporting. Problem areas should be clearly identified. Although the following is not intended to be prescriptive, zones could be:

- divided in relation to their discreteness within the system (i.e. mainly serviced by a single main, water source or water treatment plant)
- identified as discrete geographical areas that can be recognised by supply operators and the community
- large enough so that the sampling frequency will yield sufficient results to provide reasonable confidence that water is of satisfactory quality (See Chapter 10).

9.6.3 WHAT AND WHERE TO MONITOR

From the water supplier's perspective, some characteristics such as microbial parameters may need to be monitored within the distribution system or at the boundary of the consumer's property. Many physical and chemical characteristics, however, do not change, or change only slowly, within the distribution system, and it is more efficient to analyse for these characteristics closer to the water source. The monitoring sites for each physical and chemical characteristic proposed in the ADWG have therefore been chosen on the basis that it is unlikely that the characteristic will change further into the distribution system.

In reticulated water supplies, physical and chemical water quality characteristics can be divided into different types for monitoring purposes, as shown in Table 9.3.

Table 9.3 *Monitoring required for different types of physical and chemical characteristics*

Characteristic	Examples	Type of monitoring required
Substances for which the concentration depends mainly on the concentration in the water entering the supply and is unlikely to vary in the distribution system	Arsenic, cyanide, fluoride (where fluoridation is not practised), hardness, pesticides, sodium, selenium, sulfate and total dissolved solids	Generally sufficient to sample either the raw water or the water going into the supply [a]
Substances that change in concentration within the distribution system	Aluminium, disinfection residuals and byproducts, iron, manganese, colour, turbidity, taste, odour and pH	Requires sampling the raw water and/or water in the distribution system
Substances for which the distribution system provides the main source	Corrosion products such as cadmium, chromium, lead, zinc and copper	Requires sampling from the distribution system

a – here two or more waters with different concentrations of the characteristics feed the same distribution system, additional sampling may be required within the distribution system.

Tables in Chapter 10 (Tables 10.7) provide a guide on what to measure, and where to measure it, for both operational and system performance purposes. Emphasis should be placed on monitoring those characteristics identified as key characteristics for a water supply system.

Choosing sampling locations

Sampling points must provide data that are representative of the water in that particular component of the system. To establish such points, short-term investigative monitoring programs may be needed. Samples should be included from:

- the raw (source) water
- the treatment plant (for process control, not performance assessment)
- the treated (finished) water
- the headworks of the distribution system
- service reservoirs
- representative fixed and/or random sample points within the distribution system
- points representative of the quality of water supplied to consumers
- consumers' taps for specific investigations (e.g. investigation of corrosion products or to verify distribution sampling points)
- points where previous samples have revealed unsatisfactory water quality.

Routine distribution samples may be taken from either fixed or random sample points. For trend assessment, water from a series of fixed points (to overcome spatial variability) should be tested at regular intervals, and this should be complemented by random samples.

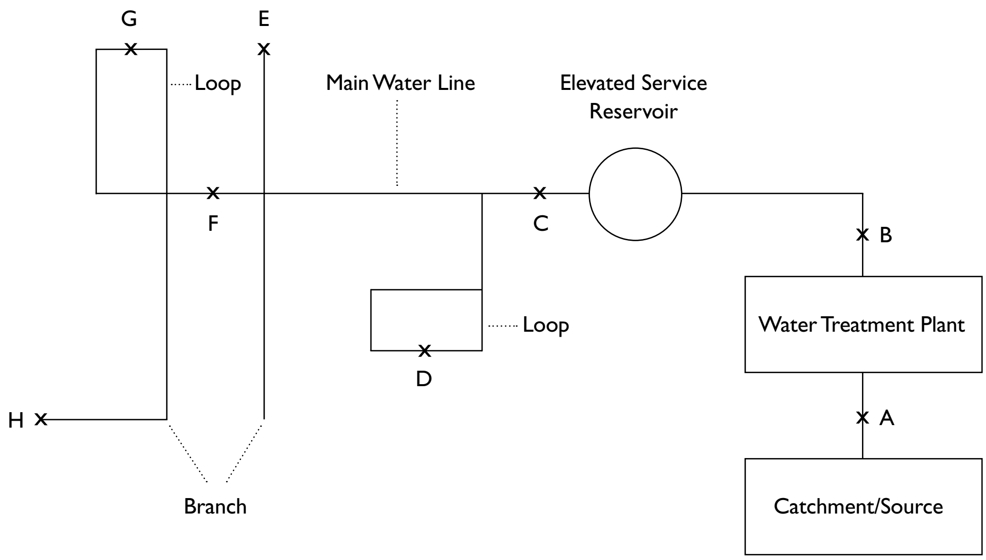
When selecting sample points within the distribution system, the following factors should be considered:

- The distribution of sample points throughout the system, including the extremities, must reflect the numbers of people supplied by the different parts of the system, especially for systems drawing on surface water. For instance, if five per cent of consumers are serviced by distribution loops, then five per cent of samples should be taken from distribution loops.
- Water quality in a given pressure zone can be affected by the specific conditions in that zone; therefore, each pressure zone must be adequately monitored.
- When a system has more than one water source, the location of sample points must be in relative proportion to the number of people served by each source, and sample points must be located at the entry points to the system for the different sources. Similarly, systems with one source and more than one treatment plant must be sampled at the entry point from each plant to the system. Any areas where supply is likely to alternate between different sources should be sampled, as such changes may be noticeable to the consumer and be a source of complaint.
- If a service reservoir has no sampling tap, a sample point should be located sufficiently close to the reservoir to represent the water quality within the reservoir.

The system in Figure 9.1 is representative of a town with a population of approximately 5000 people with one source of water. A similar approach should be used by larger authorities to determine sampling points within supply districts of larger schemes. The selected sample points used in this example would satisfy the requirement to sample as close as practicable to the point of use, and to sample over the whole water supply system.

***Figure 9.1** Example of a water distribution system for 5000 people*

- Point A is representative of the quality of raw water.
- Point B is representative of the quality of water leaving the treatment plant.
- Point C is representative of the water quality within the elevated service reservoir.
- Points D and G are representative of water quality in a distribution loop such as in a sub-development.
- Points E and H are representative of the water quality in a branch line or a branch line dead end.
- Point F is representative of water in the main line.
- Points D to H are representative of the quality of water supplied to consumers.



9.6.4 WHEN AND HOW OFTEN TO SAMPLE

How often a key characteristic should be sampled will depend on its variability, and whether it is of aesthetic or health significance. Sampling and analysis are required most frequently for microbial constituents, and less often for health-related organic and inorganic compounds. A thorough appraisal should be made when a new water source is used and immediately following any major change in treatment processes.

For both the initial baseline survey and the ongoing monitoring program, sufficient samples must be collected over a representative period to enable the data for each characteristic to be statistically evaluated, significant trends or changes identified, and performance against the ADWG assessed. The number of samples required depends on the desired level of precision with a known degree of confidence. Generally the closer the mean value of a characteristic is to the guideline value, and the greater its variability, the greater the number of samples required to assess performance (see Information Sheet 3.3).

For small supplies it may take several years to accumulate sufficient data for statistical evaluation.

Minimum sampling frequencies are given in the monitoring tables included in Chapter 10. The frequencies are suggested minimums only; local knowledge and experience based on the variability of different characteristics and the size of the water supply scheme may dictate different frequencies. Individual water supplies need to work out their own monitoring needs; however, the minimum sampling frequency recommended for most key physical and chemical characteristics is monthly when the population serviced is greater than 5000, and six-monthly for smaller populations.

Consideration should be given to the use of cost-effective surrogate characteristics as indicators of overall water quality, as discussed above (see Section 9.3).

9.7 Monitoring of consumer satisfaction

The performance of a water supply system over time is an important issue for consumers. System performance is often judged by the degree of consumer satisfaction with the quality of the supply, together with the results of analytical tests for a variety of water quality characteristics.

Consumer satisfaction is a significant consideration and will be determined by a number of factors, including:

- the consumer's own assessment of water quality, based on taste, odour and appearance
- information provided by water and health authorities
- confidence in the existing processes for providing information and dealing with water quality issues.

Consumer satisfaction with the quality of water is largely based on people's judgment that the physical quality of water at their tap is 'good' - that it is colourless and free from unpleasant taste and odour. From the consumer's point of view, changes from the norm are particularly noticeable. At present there are no guidelines for consumers' overall impressions or perceptions of physical water quality. It is important to realise that consumer satisfaction may have a regional or even local context, and that it needs to be negotiated at this level.

Experience from major water suppliers indicates that consumer satisfaction has the following characteristics:

- Consumer complaints and concerns about 'healthiness' are driven more by sudden noticeable changes in quality, particularly in taste, odour, colour and turbidity, than by the long-term average.
- Taste and odour associated with disinfectants are tolerated up to a point because they are associated with the protection of public health, although concerns sometimes arise about the health effects of added chemicals.
- It is unrealistic to expect to achieve complete satisfaction. It is unlikely that more than 90 per cent of consumers will give a 'good to excellent' rating on taste and odour.
- The bulk of consumer complaints relate to taste and odour, discolouration and stained washing, many of which stem from household plumbing or are very localised. It is the unusual complaints such as the fishy smell generated by the presence of certain algae in the water, or blue discolouration due to corrosion of the consumer's copper service pipes, which may have much wider implications for the water supply system, and these require immediate attention.

The physical characteristics of water quality are largely surrogate descriptors, in that no single characteristic really measures what the consumer perceives. It may therefore be appropriate to negotiate levels of service or set internally a more direct measure of consumer acceptance, such as complaint rates for taste, odour and appearance based on local circumstances. Some examples of objectives that could be used are:

- to achieve fewer than four water quality complaints per thousand households per year for unfiltered (but disinfected) supplies, and fewer than two water quality complaints for filtered supplies
- to obtain a 'good to excellent' score for water quality at the tap from more than 80 per cent of consumers.

9.8 Investigative and research monitoring

Investigative and research monitoring can be used to increase understanding of a water supply system, identify and characterise potential hazards, and fill gaps in knowledge. By improving understanding of the factors affecting water quality characteristics, such monitoring allows suppliers to anticipate periods of poor water quality and respond to them effectively.

9.8.1 BASELINE MONITORING

Baseline monitoring of all new water supplies and of potential water supplies under consideration is imperative in order to:

- define the key characteristics that should be measured routinely
- identify major water quality problems
- provide an indication of the need for water treatment
- establish a base for assessing long-term trends and variability in water quality
- compare and select source waters for future supply.

In the absence of other data or information, baseline monitoring should be carried out for all health-related characteristics listed in the ADWG. Exceptions may be some chemicals not reasonably expected to be present or for which sampling is not practicable.

Initial baseline monitoring should be carried out for new water supplies as a basis for ongoing monitoring. Baseline monitoring of new water supplies and those not previously sampled should include sampling to characterise the radiological quality of the water supply. The extent of sampling and the timeframe required to make a baseline assessment will depend on land use in the catchment, levels of pollution found and variability or trends in water quality.

An initial land-use survey of the catchment should be undertaken to:

- identify existing and planned developments
- assess potential continuous, intermittent or seasonal pollution patterns
- assess geological features likely to affect water quality
- identify chemicals used in catchments
- locate existing or abandoned waste-disposal or mining sites.

Where catchments and supplies are beyond the water supplier's jurisdiction, exchange of information and collaborative assessment of the quality of source waters is strongly advocated.

Initial investigative monitoring has a number of limitations:

- not all potential water quality problems may be recognised and long-term trends or variability in water quality may be difficult to anticipate
- the comprehensiveness of baseline and follow-up monitoring may be limited by the available human or laboratory resources
- the impacts for harvesting, storage, treatment and distribution of water may not be fully appreciated.

Nevertheless, it is essential that an attempt be made to characterise source waters before they are used for water supply. If sampling is initiated only when the supply is commissioned, major water quality problems that might otherwise have been anticipated could result in long-term operational problems.

An existing sampling database makes a good starting point for establishing a baseline. The baseline, however, will change as land use changes, and new characteristics may need to be monitored. Follow-up sampling regimes are required to assess significant changes in water quality arising from:

- impacts of water abstraction (this is particularly important for water from unconfined aquifer systems)
- changed land-use practices
- longer term natural variability in water quality that may not have been evident from initial baseline monitoring.

9.8.2 EMERGENCY RESPONSE MONITORING

The frequency of monitoring should be increased in response to any emergency or incident. Emergency incident plans need to take into consideration the capability and availability of water and laboratory personnel.

9.9 References

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