PART IV INFORMATION SHEETS

Disinfection of drinking water

INFORMATION SHEET 1

Disinfection is the single process that has the greatest impact on drinking water safety, resulting in substantial decreases in waterborne disease. Disinfection is generally accomplished either alone or as the final step following clarification of water in a water treatment plant.

Agents and processes used to disinfect water include chlorine, chloramines, chlorine dioxide, ozone, ultraviolet (UV) and ionising radiation, bromine, bromine chloride, iodine, silver and silver compounds, filtration and changes to physical and chemical properties. Information Sheets 1.2–1.7 describe the commonly used processes used for disinfection.

The information given here should be read in conjunction with Section 6.3.2 on the chemical byproducts of disinfection.

PROPERTIES OF AN IDEAL DISINFECTANT

An ideal disinfectant should:

- effectively remove pathogens over a range of physical and chemical conditions
- produce a disinfectant residual that is stable and easily measured
- produce no unacceptable byproducts
- be easily generated, safe to handle and suitable for widespread use
- be cost effective.

No disinfectant currently in use meets all of these criteria. The choice of disinfectant will depend on the quality of the source water, the origin of the contaminating microorganisms, the length and complexity of the system and the size of the population served.

PRETREATMENT OF WATER

The physical quality (particularly turbidity and pH) of the water should be improved before disinfection to decrease the likelihood that disease-causing organisms or pollutants will be harboured in suspended matter, and to increase the efficiency of disinfection. Generally, turbidity of less than one nephelometric turbidity unit is required for effective disinfection.

EFFECTIVE DISINFECTION

The effectiveness of disinfection depends on:

- the nature and concentration of the disinfecting agent
- the type of microorganisms present
- contact time (the length of time the disinfectant is available for inactivation)
- satisfactory mixing of disinfectant and target microorganisms
- the degree to which the microorganisms are protected by
  – adsorption to, or inclusion in, solid particles
  – attachment to surfaces of pipes or fittings
- the level of competing inorganic and organic reactants
- turbidity, temperature and pH.

Turbidity, the concentration of the disinfectant, contact time and pH can all be monitored continuously, and can provide a useful indication of microbial quality control.

MAINTAINING EFFECTIVE DISINFECTION

Disinfection is of paramount importance in controlling microbial quality. Particular attention should be paid to the following points:

- Operational factors affecting microbial quality (e.g. pH, disinfectant residual and turbidity) should be monitored frequently (daily or preferably continuously).
- No animal or plant material should be directly visible.
- A minimum total chlorine residual should be present (0.5 mg/L after 30 minutes) if chlorination is used.
- Turbidity should be low (preferably < 1 nephelometric turbidity unit).
- The pH should be optimised to suit the disinfectant used (subject to the need to minimise corrosion).
- If the water temperature is more than 30°C, the water should be monitored for amoebae.
- The reticulation system should be adequately maintained.
- The levels of disinfectant residual in the distribution system should be monitored frequently.

DETERMINING THE EFFECTIVENESS OF A DISINFECTANT

The C.*t* concept describes the relative effectiveness of a specific disinfectant against different microorganisms under specified conditions. It is determined by multiplying the concentration of residual disinfectant (in mg/L) by the contact time (in minutes). The C.*t* concept is expressed mathematically as:

$$k = C^n . t$$

where: C = concentration of residual disinfectant

n = constant (also called the coefficient of dilution)

t = contact time required for a fixed per cent of inactivation

k = constant for a specific microorganism exposed under set conditions.

Several disinfection experiments are required to determine the time to achieve a 99% kill of a test microorganism using different concentrations of the disinfectant under specific conditions. Log-log plots of the results generally result in a straight line with slope n. If the specific conditions such as the pH or temperature during chlorination are varied, then several lines result, which still follow the general C.*t* equation. Reported values for n range from 0.5 to 1.8 for most aqueous disinfectants. Generally, however, n approximates 1, and the equation is simplified to $k = C.t$.

C.*t* values for specific organisms exposed to particular disinfectants can be calculated from the graphs. A low C.*t* value indicates a strong primary disinfectant. Comparative disinfection efficiencies, based on the C.*t* concept, of four major disinfectants for *Escherichia coli,* two viruses, bacteriophage f_2 and protozoan cysts are summarised in table IS1.1.

Microorganisms are generally very susceptible to ozone, chlorine dioxide and chlorine, but less so to monochloramine. The relative speed of action of disinfectants, from most to least effective, is ozone, chlorine dioxide, hypochlorous acid, hypochlorite ion, dichloramine and monochloramine. Increased speed of action means a shorter contact time is required, increasing the flexibility of the system.

Caution should be used in applying C.*t* values to disinfection practice in the field because:

- disinfection data do not always follow exponential rates
- different isolates of the same species may have different disinfection rates, and rates also vary between different species and types of organisms
- no consideration is given to the state of growth, protection and adsorption of microorganisms, mixing, variation in disinfectant concentration, and inactivation rates
- laboratory data obtained under ideal conditions do not always relate to field conditions.

Table IS1.1 *Summary of C.t value ranges for 99% inactivation of various microorganisms by disinfectants at 5°C*

Microorganisms	**Free chlorine pH 6–7**	**Preformed chloramine pH 8–9**	**Chlorine dioxide pH 6–7**	**Ozone pH 6–7**
Escherichia coli	0.034–0.05	95–180	0.4–0.75	0.02
Polio 1	1.1–2.5	768–3740	0.2–6.7	0.1–0.2
Rotavirus	0.01–0.05	3806–6470	0.2–2.2	0.006–0.6
Phage f_2	0.08–0.18	–	–	–
Giardia intestinalis cysts	47– >150	–	–	0.5–0.6
Giardia muris cysts	30–630	–	7.2–18.5	1.8–2.0

Source: Hoff JC (1986) Inactivation of Microbial Agents by Chemical Disinfectants, Report EPA/600/2–86, Water Engineering Research Laboratory, United States Environmental Protection Agency, Cincinnati, Ohio, United States.

Choice of disinfectant

INFORMATION SHEET 1.1

Each of the various ways of disinfecting drinking water has advantages and disadvantages. The most appropriate disinfectant will depend on local conditions and the choice will generally involve a compromise. The most commonly used disinfectants are chlorine, chloramine and ozone, followed by chlorine dioxide and UV irradiation (see Information Sheets 1.2–1.7). The applicability of these commonly used disinfectants is summarised in the table below.

Table IS1.2 *Applicability of disinfection techniques to different situations*

Consideration	Chlorine	Chloramination	Ozone	Chlorine dioxide	Ultraviolet
Size of plant	All sizes	All sizes	Medium to large	Small to medium	Small to medium
Equipment reliability	Good	Good	Fair to good	Good	Fair to good
Relative complexity of technology	Simple to moderate	Simple to moderate	Complex	Moderate	Simple to moderate
Safety concerns	Yes	Yes	Moderate	Yes	Minimal
Bactericidal	Good	Good	Good	Good	Good
Virucidal	Moderate	Poor	Good	Good	Good
Byproducts of possible health concern	Yes	Fewer	Significance unresolved	Yes	No
Persistent residual	Moderate	Long	None	Moderate	None
Contact time	Moderate	Moderate	Short	Moderate	Short
pH dependent	Yes	Yes	Slight	Slight	No
Process control	Well developed	Well developed	Developing	Developing	Developing

Chlorine

INFORMATION SHEET 1.2

GENERAL DESCRIPTION

Chlorine was introduced as a water disinfectant early in the 20th century and still remains the major chemical in use for this purpose around the world. It is a strong disinfectant with excellent bactericidal properties, and is effective at short contact times. It is also a strong oxidising agent that can bleach colour compounds in water, oxidise iron and manganese, and remove the tastes and odours produced by some algae.

In water, chlorine reacts to form hypochlorous acid (HOCl), a very effective disinfectant. The hypochlorous acid dissociates to form hypochlorite ion (OCl^-) which is estimated to be 150 to 300 times less effective as a disinfectant than hypochlorous acid. (See also Section V – Fact Sheet – *Chlorine*).

APPLICABILITY

Chlorine is suitable for all sizes of plant and is easy to apply either as a gas or as the hypochlorite (calcium hypochlorite powder or sodium hypochlorite liquid).

EFFECTIVENESS AGAINST MICROORGANISMS

Chlorine is highly effective against bacteria, moderately so against most viruses and is effective against the protozoan parasite *Giardia*. The concentrations of chlorine that can safely be used in disinfecting drinking water are ineffective against *Cryptosporidium*.

GENERAL CONSIDERATIONS FOR USE

Reliable equipment is available for chlorination, the technology involved is simple to moderate and controls for the process are well developed. Natural water contains inorganic and organic compounds that react with chlorine. Sufficient disinfectant must be used to satisfy this demand and still provide the required dose for disinfection.

TURBIDITY AND PH

Turbidity should be less than one nephelometric turbidity unit. Chlorination requires a pH of less than 8 because the relative proportions of HOCl and OCl^- in solution depend on pH and, to a lesser extent, on temperature. Lower pH and temperature result in higher proportions of HOCl:

- at 0ºC and pH 7, 83% exists as HOCl
- at 0ºC and pH 8.5, 14% exists as HOCl.

Decreasing the pH at the point of disinfection increases the efficiency of chlorine disinfection (by increasing the proportion of HOCL relative to OCl^-), but also increases the corrosion potential of the water.

CONTACT TIME AND PERSISTENT RESIDUAL

In clean water, a combined available residual chlorine level of 0.5 mg/L after a contact time of 30 minutes should be sufficient to ensure microbial control, given a clean distribution system and no significant recontamination.

Maintaining a persistent chlorine residual throughout the distribution system can be difficult, particularly in long distribution systems. However, in a number of treated water supply systems in Europe where treatment (including disinfection) produces a biologically stable water that will not support microbial growth, chlorine residuals can be maintained within the distribution system. In such systems, the loss of a chlorine residual can highlight an area of contamination and the need for remedial action. The extensive water treatment practised and the minimal chlorine doses used also minimise levels of disinfection byproducts.

BYPRODUCTS OF POSSIBLE HEALTH CONCERN

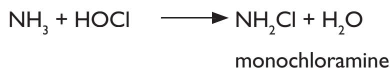
Reactions with naturally occurring organic matter produce chlorinated byproducts, particularly the trihalomethanes. Chlorine may also react with compounds such as phenols to impart a taste and odour to water.

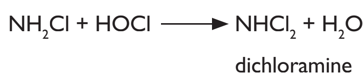
Chloramines

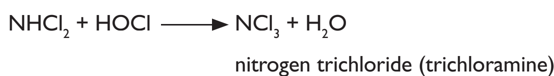
INFORMATION SHEET 1.3

GENERAL DESCRIPTION

Chloramines (principally monochloramine) are formed when chlorine and ammonia are added to water:







Dichloramine is a stronger disinfectant than monochloramine, but is less stable and has a distinct disagreeable odour. Nitrogen trichloride has an extremely offensive odour, but is readily destroyed by sunlight.

Chloramines are weaker oxidising agents than chlorine; therefore, they are less likely to cause undesirable tastes and odours by oxidation of natural organics, but are also less likely to reduce tastes and odours produced by algae.

APPLICABILITY

Chloramination is suitable for all sizes of plant. Field results from most Australian systems that use chloramine indicate satisfactory primary disinfection capability and continued protection in reticulation systems. Chloraminated water is unsuitable for use in renal dialysis; the chloramine must first be removed by activated carbon filters.

EFFECTIVENESS AGAINST MICROORGANISMS

The biocidal activity of chloramines is slower than that of free chlorine. Chloramine is effective against bacteria but its activity against viruses is poor.

GENERAL CONSIDERATIONS FOR USE

Reliable equipment is available for chloramination, the technology involved is simple to moderate and controls for the process are well developed. To ensure that monochloramine is the major species formed at normal pH levels (7.5–8.0), the ratio of chlorine to ammonia is controlled at levels of 3:1 to 5:1.

Problems have occurred with open online storages where nitrification and the loss of chloramine residuals result in high levels of nitrite nitrogen at the ends of systems. Nitrification also accelerates the loss of chloramine, and often requires chlorination of infected storages to eliminate nitrifying bacteria and re-establish the chloramine residual.

TURBIDITY AND pH

Turbidity should be less than one nephelometric turbidity unit. Chloramination requires a pH of 8–9 because low pH (together with a high ratio of chlorine to ammonia) favours the formation of the less stable chloramines.

CONTACT TIME AND PERSISTENT RESIDUAL

Monochloramine is a weak disinfectant; it requires a contact time of many hours and a residual of 1.5 mg/L to be effective. However, chloramine persists in distribution systems and continues to disinfect in the extremities of long systems. The high stability of chloramines can be a disadvantage in some instances. Low levels of chloramines are acutely toxic to a variety of aquatic organisms and this must be considered when introducing chloramines to storages and aquariums.

BYPRODUCTS OF POSSIBLE HEALTH CONCERN

Provided that chloramines are formed by pre-ammoniation, chloramination produces considerably lower concentrations of trihalomethanes and other chlorinated byproducts than chlorination. Chloramination produces higher concentrations of cyanogen chloride than does chlorination, but the concentrations detected are still considerably lower than the guideline value for this compound (See also Section V – Fact Sheet – *Cyanogen chlorine*). No additional byproducts have been identified as a result of chloramination.

Chlorine dioxide

INFORMATION SHEET 1.4

GENERAL DESCRIPTION

Chlorine dioxide is a reactive gas that cannot be easily stored or transported, and must be generated on site. In Europe this is usually done by acid treatment of sodium chlorite, which generates the gas with little or no chlorine contamination and so avoids the formation of chlorinated byproducts during disinfection.

Chlorine dioxide is a more effective disinfectant than chlorine, although the overall kinetics of bacterial destruction appear to be similar. It has excellent oxidising ability, which reduces taste, minimises colour and oxidises iron and manganese complexes.

APPLICABILITY

Chlorine dioxide is a suitable disinfectant for a small to medium sized water treatment plant. It has been used mainly as a preoxidant (rather than as a primary disinfectant) to control taste and odour, remove iron and manganese, and more recently, remove trihalomethane and total organic halogen (TOX) precursors. In some supplies chlorine dioxide has been used in combination with chloramination.

EFFECTIVENESS AGAINST MICROORGANISMS

Chlorine dioxide has excellent biocidal activity; it is effective against bacteria and viruses.

GENERAL CONSIDERATIONS FOR USE

Reliable equipment is available for disinfection with chlorine dioxide, the technology involved is moderately complex and controls for the process are developing. In raw water, chlorine dioxide is rapidly consumed and volatilised, and this is a major disadvantage.

TURBIDITY AND pH

Turbidity should be less than one nephelometric turbidity unit. Disinfection with chlorine dioxide requires a pH of less than 8. Its effectiveness increases about three-fold between pH 6 and 9.

CONTACT TIME AND PERSISTENT RESIDUAL

The dose of chlorine dioxide required is 1–2.5 mg/L or slightly higher, with residuals of 0.3 mg/L or less, for a contact time of 30 minutes. Chlorine dioxide provides a moderately persistent residual.

BYPRODUCTS OF POSSIBLE HEALTH CONCERN

End products from the use of chlorine dioxide include chloride ions, chlorite ions, chlorate ions and residual chlorine dioxide. The oxidative end products have been found to be a health hazard. (See also Section V – Fact Sheet – *Chlorine dioxide*)

Ozone

INFORMATION SHEET 1.5

GENERAL DESCRIPTION

Ozone is generated on site by passing an electric discharge through clean dry air or oxygen. The resultant ozone is a very strong biocide and oxidising agent and is effective in reducing colour, iron, manganese, taste and odour.

APPLICABILITY

Ozone can be used in medium to large treatment plants although it has not been used in Australia to date for the disinfection of sizeable potable water supplies. It reacts with natural organics to produce lower molecular weight compounds, which are more biodegradable and promote the growth of bacteria in distribution systems. This can be used to advantage in biological filtration processes. Ozonation can break up high molecular weight organics before filtration through a bed of granular activated carbon, and the resulting low molecular weight compounds can be used by bacteria that grow on the carbon, thereby reducing organic concentrations in the water. In Europe, ozone has a long history of use for disinfection and for the control of taste, odour and colour. Ozone is more expensive than chlorine and has low solubility in water.

EFFECTIVENESS AGAINST MICROORGANISMS

Ozone is effective against bacteria and viruses.

GENERAL CONSIDERATIONS FOR USE

The equipment used for ozonisation is fairly reliable but the technology involved is complex and process controls are developing. Ozone is highly sensitive to turbidity.

TURBIDITY AND PH

Turbidity should be less than one nephelometric turbidity unit. The pH should be less than 8 for effective disinfection because ozone is unstable above pH 8 (at pH 8, half of the ozone is lost in less than 30 minutes).

PERSISTENT RESIDUAL

Due to its low solubility in water and instability above pH 8, an ozone residual cannot be maintained in a distribution system, particularly as temperature increases.

BYPRODUCTS OF POSSIBLE HEALTH CONCERN

Ozone is a powerful oxidant and can convert naturally occurring bromide to bromine, and this can lead to the formation of brominated trihalomethanes (THMs). However, the brominated THMs produced in ozonation usually occur in lower concentrations, and constitute less of a problem, than chlorinated THMs produced by chlorination. Interest in ozonation has increased significantly in the United States in recent years since the adoption of stringent limits for trihalomethanes and because of the need for a strong oxidant and primary disinfectant to replace chlorine for pretreatment.

Low molecular weight aldehydes such as formaldehyde and acetaldehyde have also been detected as byproducts of ozonation.

Ultraviolet light

INFORMATION SHEET 1.6

GENERAL DESCRIPTION

Ultraviolet light (UV) is generated by low-pressure mercury lamps. UV irradiation disrupts the chemical bond of many organic molecules and hence is a potent disinfectant.

UV irradiation has a minimal effect on the chemical composition or taste of the water. Overdosing presents no danger and is sometimes contrived as a safety factor.

APPLICABILITY

UV irradiation is applicable to small or medium sized treatment plants. Internationally, UV irradiation has found numerous applications in situations where lack of a disinfection residual is not important, such as point-of-use disinfection in hospitals.

EFFECTIVENESS AGAINST MICROORGANISMS

UV irradiation is effective against bacteria and viruses. It causes specific deleterious changes in the nucleic acid of cells, resulting in death or mutation such that the cell is no longer capable of division. Microorganisms may, however, become viable again in the presence of visible light (photoreactivation) if UV disinfection is inadequate. Varying intensities of UV irradiation are required for removal of different microorganisms, with the recommended dose being of the order of 16–46 mW–sec/cm^2; the higher dose is roughly equivalent to chlorine in instantaneous disinfection efficiency.

GENERAL CONSIDERATIONS FOR USE

The equipment required for UV irradiation is fairly reliable, the technology required is relatively simple and controls for the process are being developed. High colour and turbidity and the presence of metals and organic matter reduce the amount of UV radiation reaching microorganisms and necessitate higher doses of applied radiation for effective disinfection. Units require regular cleaning and maintenance to remain effective.

TURBIDITY AND PH

Turbidity should be less than one nephelometric turbidity unit. UV irradiation is not pH dependent.

CONTACT TIME AND PERSISTENT RESIDUAL

UV requires only a short contact time, but has a disadvantage in that it leaves no residual disinfectant.

BYPRODUCTS OF POSSIBLE HEALTH CONCERN

Few data are available on the byproducts of UV disinfection; however, the potential to produce organic byproducts is minor because the intensities required for UV disinfection are less than those needed to cause photochemical effects.

Other disinfectants

INFORMATION SHEET 1.7

BROMINE

Bromine has been widely used to disinfect swimming pools through the addition of solid bromine-releasing agents such as N-bromo-N-chloro-5,5-dimethylhydantoin or dibromocyanuric acid. Bromine chloride (BrCl) is under investigation for large-scale use, such as control of biofouling in cooling towers or wastewater disinfection, as it is much less corrosive than liquid bromine and has sufficient vapour pressure to enable it to be metered in equipment similar to that used for chlorine.

IODINE

Iodine has been used as a disinfectant for small drinking water supplies; however, like bromine, it is costly to use on a municipal scale. It is not recommended for regular use as a disinfectant due to possible health effects associated with long-term consumption. It can, however, be used for emergency water disinfection. (See also Section V – Fact Sheet – *Iodine*).

POTASSIUM PERMANGANATE AND HYDROGEN PEROXIDE

Potassium permanganate and hydrogen peroxide are effective disinfectants that are not used in large-scale plants, but may be used in small-scale or emergency applications. Recently, hydrogen peroxide has been used in conjunction with ozone (peroxone) to provide a more effective oxidising agent, particularly to remove taste and odour metabolites. Peroxone and ozone are equally effective for disinfection.

HEAT

Heat is the traditional emergency disinfectant, and boiling water under normal conditions will kill most pathogens.

SILVER

Silver is a weak biocide that has been used occasionally for disinfection, particularly with point-of-use devices. (See also Section V – Fact Sheet – *Silver)*.

ULTRASONICS AND ULTRAFILTRATION

Ultrasonics can disintegrate microorganisms and ultrafiltration of waters can remove microorganisms: these methods are used for special applications.

EXTREMES OF PH

Altering the pH to greater than 12 or less than 2 will kill microorganisms; however, this is not recommended for permanent water supplies as it causes adverse health effects, and also affects distribution system pipework. As with many of the alternative disinfectants listed here, such an option is relatively expensive and is only considered for small-scale, emergency, or specialist applications. (See also Section V – Fact Sheet – *pH*).

Sampling Information – handling requirements and preservation

INFORMATION SHEET 2.1

This sheet gives information of general handling requirements for heavy metals, filterable metals, organic compounds and pesticides and microbial characteristics, and a summary of the special handling requirements for sampling for physical, chemical and radiological characteristics.

SAMPLING FOR HEAVY METALS

Treatment of the sample with acid at the time of collection places the metals in solution and prevents adsorption or deposition on the container walls. 1.5 mL of concentrated nitric acid per litre of sample is usually sufficient for short-term preservation. The sample should be stored at approximately 4ºC. It will be stable for up to 28 days.

Some laboratories will supply acid-washed bottles with the acid preservative. When such bottles are not available, samples should be collected in acid-washed bottles, and preserved immediately by acidifying with concentrated nitric acid to $pH < 2$. The advice of the analyst should be sought prior to taking a sample.

Mercury and chromium have special requirements. An analyst should be consulted before collection of samples.

Procedure for acid washing:

1. Wash bottle and cap with a metal-free, nonionic detergent and tap water.
2. Rinse thoroughly with tap water.
3. Rinse with one part distilled water, one part concentrated nitric acid.
4. Drain and fill with one part concentrated nitric acid, fourteen parts water.
5. Cap and store until required, but for at least a week.
6. Empty before use, rinse with metal-free water such as distilled water.

Metals can be divided into various fractions as determined by the analytical Information:

- Filterable metals (soluble or dissolved metals) – those constituents of an unacidified sample that pass a 0.45 µm membrane filter.
- Suspended metals – those constituents of an unacidified sample that are retained on a 0.45 µm membrane filter.
- Total metals – the concentration of metals determined on an unfiltered sample after vigorous digestion, or the sum of the concentrations of metals in both the filterable and suspended fractions. Total metals include all metals inorganically and organically bound, both filterable and particulate.
- Acid-extractable metals – the concentration of metals in solution after treatment of an unfiltered sample with hot mineral acid.
- Readily acid-soluble aluminium (see Section V – Fact Sheet – *Aluminium*).

The fraction(s) to be analysed will determine the requirements for sample handling and preservation. It is generally advisable to collect two samples, one for total metals and one for dissolved metals.

PRELIMINARY FILTRATION FOR FILTERABLE METALS

The membrane filter and filter device should be preconditioned by rinsing with deionised or distilled water, or soaking the membrane filter and filter device in approximately one part distilled water, one part nitric acid, and rinsing with deionised or distilled water before use.

- Before use, a blank consisting of deionised or distilled water should be filtered to ensure freedom from contamination.
- The sample should be filtered as soon as possible after collection, discarding the first 50 mL of filtrate, and the filtrate should be acidified with nitric acid to below pH 2.
- If suspended metals are to be determined, the filter should be retained for digestion.

Care must be taken to avoid introducing contaminating metals from containers, lids, distilled or deionised water, acid preservative, or membrane filters; or from airborne contaminants in the form of smoke, dust, soot or aerosols.

SAMPLING FOR ORGANIC COMPOUNDS AND PESTICIDES

Because organic compounds and pesticides, if present at all, are likely to occur only in very low concentrations, considerable care is needed in choosing and preparing sample containers. Bottles supplied by the analyst should be used, and the analyst's instructions for sample handling and preservation followed. These instructions will vary with the compound being analysed and the methods of analysis used by the laboratory.

SAMPLING FOR MICROBIAL CHARACTERISTICS

- Sufficient sodium thiosulfate should be added to the sample bottle to neutralise all residual chlorine.[1]
- A chelating agent should be used in bottles receiving water containing copper, zinc or other heavy metals.
- Drinking water samples should be taken directly from a service pipe, not from an intermediate tank or cistern.
- The bottle should not be filled to the top (leave an air space of at least 2.5 cm).
- An ice-filled cooler should be used to transport samples to the laboratory.

The sample should, ideally, be analysed within 6 hours. Under exceptional circumstances the elapsed time may exceed 6 hours, but should not exceed 24 hours. If 6 hours is exceeded, the time interval should be reported with the results.[2]

1 – APHA Method 9060, (1992), Microbiological Examination: Samples, Standard Methods for the Examination of Water and Wastewater. 18th Edition, American Public Health Assoc., Wahington, United States

2 – AS 2031.2, (1987), Selection of containers and preservation of water samples for chemical and microbiological analysis. Part 2: Microbiological, Standards Association of Australia

Table IS2.1 *Special handling requirements for sampling for chemical, physical and radiological characteristics*[3]

Characteristic	Container	Minimum sample size (mL)	Preservation procedure	Maximum holding period	Comments
Aluminium	P(A), G(A)	100	Add HNO_3 to pH < 2	28 days	
Arsenic	P(A), G(A)	500	Add HNO_3 to pH < 2	28 days	
Boron	P	500	None required	28 days	
Cadmium	P(A), P(G)	500	Add HNO_3 to pH < 2	28 days	
Chloride	P, G	100	None required	6 months	
Chlorine residual	P, G	200	Analyse immediately	5 minutes	Keep sample out of direct sunlight
Chromium (total)	P(A), G(A)	500	Add HNO_3 to pH < 2	28 days	
Chromium (VI)	P(A), G(A)	1000	Refrigerate	24 hours	Avoid adding reagents
Colour	P, G	100	Refrigerate	24 hours	
Copper	P(A), G(A)	500	Add HNO_3 to pH < 2	28 days	
Cyanide (total)	P, G	500	Add NaOH to pH > 12, refrigerate in the dark	24 hours	Remove sulfide
Fluoride	P	500	None required	28 days	
Hardness	P, G	200		7 days	
Iron	P(A), G(A)	100	Add HNO_3 to pH < 2	28 days	
Lead	P(A), G(A)	500	Add HNO_3 to pH < 2	28 days	
Manganese	P(A), G(A)	500	Add HNO_3 to pH < 2	28 days	
Mercury	G(B), (A)	500	Add HNO_3 to unfiltered sample to pH < 1. Add $K_2Cr_2O_3$		Consult analyst for further instruction
Metals (general)	P(A), G(A)		Add HNO_3 to pH < 2	28 days	
Metals (filterable)	P(A), G(A)		Filter immediately, add HNO_3 to pH < 2	28 days	0.45 μm filter
Nitrate	P, G	500	1. Refrigerate or	6 hours	Consult analyst – depends on analytical method
			2. Freeze immediately or	7 days	
			3. Add H_2SO_4 to pH < 2 and refrigerate	7 days	
Odour	G	500	Analyse as soon as possible; refrigerate	6 hours	
Oxygen, dissolved	G(A)	300	1. Electrode: analyse immediately on site	*In situ*	Consult with analyst. Store in dark
			2. Winkler: titration may be delayed after acidification	24 hours	
Pesticides					
1. Organo-phosphates	G(S)	2000	No reference available	No reference available	Consult with analyst
2. Others	G(S)	4000	Solvent-extract on-site with appropriate solvent; refrigerate	24 hours	If residual chlorine present , add 1000 mg/L ascorbic acid. Consult with analyst

3 – Data complied from AS 2031.1–1986, Selection of Containers and Preservation of Water Samples for Chemical and Microbiological Analysis, Part 1–Chemical, APHA Method 1060 (1992).

Table IS2.1 Special handling requirements for sampling for chemical, physical and radiological characteristics[3] (Continued)

Characteristic	Container	Minimum sample size (mL)	Preservation procedure	Maximum holding period	Comments
pH	P, G(B)	100	Analyse immediately; determine on site or *in situ*	6 hours	
Polycyclic aromatic hydrocarbons (PAH)	G(S)	2000	1. Add 1000 mL of methanol to container before adding an equal volume of sample; or	7 days	
			2. Add extracting solvent on site	24 hours	
Radioactivity gross *alpha* and *beta* activity	P(A), G(A)	1000	Add HNO_3 to pH < 2	28 days	Consult with analyst
Selenium	P(A), G(A)	1000	Add HNO_3 to pH < 2	28 days	
Sodium	P	100	None required	28 days	
Sulfate	P(A)	200	Refrigerate	7 days	
Taste	G	500	Analyse as soon as possible, refrigerate	24 hours	
Temperature	–	–	Analyse immediately allowed	No storage allowed	Determine in situ
Total dissolved solids	P, G	500	Refrigerate	28 days	
Trihalomethanes	G(S)	100	Add 2 mL of 5% ascorbic acid solution. Fill bottle to brim.	21 days	
Turbidity	P, G	100	Analyse same day, store in dark, refrigerate	24 hours	Preferably determine on–site or *in situ*
Zinc	P(A), G(A)	500	Add HNO_3 to pH < 2	28 days	

Container	P	= Plastic (polyethylene or equivalent)
	G	= Glass
	G(B)	= Glass, borosilicate
	P(A), G(A)	= Rinsed with 50% HNO_3
	G(S)	= Glass, rinsed with organic solvent
Preservation	Refrigerate	= Store between 1 and 4°C in the dark, do not freeze
	HNO_3	= Nitric acid (hydrochloric acid may be used in this context but nitric acid is preferred)
	NaOH	= Sodium hydroxide solution (40% w/v)
	H_2SO_4	= Sulfuric acid
	$K_2Cr_2O_3$	= Potassium dichromate

3 – Data complied from AS 2031.1–1986, Selection of Containers and Preservation of Water Samples for Chemical and Microbiological Analysis, Part 1–Chemical, APHA Method 1060 (1992).

Statistics – assessing performance

INFORMATION SHEET 3.1

PRELIMINARY CONSIDERATIONS

In deciding how the performance of a water supply system should be assessed, it is necessary to consider:

- the statistical implications of the assessment mechanism
- possible health implications of using different statistical measures
- community perceptions of what constitutes good quality water.

Three commonly used procedures measure performance against a maximum value, a mean or a percentile.[4]

ASSESSING PERFORMANCE AGAINST A MAXIMUM VALUE

Using this approach, performance is measured by quoting the percentage of scheduled samples tested that are below the guideline value. Although the approach is used often and is superficially easy to comprehend, it has a number of serious deficiencies:

- While measurements will show how a system is performing at the time of sampling, there is no way of determining what the water quality is like between sampling events. Statistical procedures cannot be used to indicate whether or not the measurements are representative of the quality at other times. (Other methods of assessing performance, however, can provide this information.)
- There is no way of reliably estimating what the true maximum value is, as this may well occur between samples. Any sampling program can only provide a biased estimate of the true maximum value, which it will invariably underestimate. There is always the possibility that the next sample analysed may have a higher value.
- The approach can create a real disincentive to rational planning of monitoring programs, as it may persuade water authorities to take a minimum number of samples in order to reduce the possibility of poor performance.

ASSESSING PERFORMANCE AGAINST A MEAN

Performance is assessed by comparing the mean value of measurements with the guideline value over a period (usually 12 months). Such an approach has a number of attractions:

- For characteristics not related to health, the guideline values are generally midpoints in a range of acceptability rather than maximum values, and thus it can be argued that it is the mean or average value that is significant. In many cases it is sudden large increases in a value that can bring an increased number of consumer complaints.
- Simple and well-proven statistical procedures can be used to provide statistically unbiased estimates of the mean with a known degree of confidence. The degree of confidence (or the confidence interval) will determine how well the mean represents the quality between sampling events.
- Use of a mean value encourages rational planning of monitoring programs. Water that fails to meet the guideline will encourage more sampling, and good quality water less sampling. These are positive incentives to the water manager to 'get it right'.

The disadvantage of this approach is that a few high values can be offset by a number of low values. This is less of a problem if confidence intervals are applied to the estimate of the mean.

4 – Data complied from AS 2031.1–1986, Selection of Containers and Preservation of Water Samples for Chemical and Microbiological Analysis, Part 1–Chemical, APHA Method 1060 (1992).

ASSESSING PERFORMANCE AGAINST A PERCENTILE

Using this approach, performance is satisfactory if a large percentage of results (although not necessarily all) are less than the guideline value. Like the use of a mean, this approach has a number of attractions:

- For health-related characteristics, performance could not be regarded as satisfactory if the guideline values were exceeded on more than the rare occasion. This is consistent with using a high percentile such as a 95th percentile (higher values could be used if required).
- Although this approach is slightly less satisfactory than requiring all the results to be less than the guideline value, it avoids the difficulties associated with a 'maximum value' approach. Most importantly, it is possible, using statistical procedures, to estimate with a known degree of confidence how well the results of sampling represent the quality of water at other times.
- Using a percentile to assess performance against the guideline is consistent with the requirement that the upper control limit of the control chart be equal to or less than the guideline value. Say, for example, that the 95th percentile is used. If the control limits are placed at 1.64 times the standard deviation on either side of the mean then, as discussed above, they will encompass about 90% of the data, and of the remaining 10%, about 5% will be above the upper control limit and 5% below the lower (provided the data are not skewed). This means that if the upper control limit is the same as or less than the guideline value, then 95% or more of the data should be below the guideline value.
- Poor quality water will encourage more sampling, while good quality water will encourage less sampling.
- More samples need to be analysed to assess performance against a percentile than are needed for a mean. This is reasonable for health-related characteristics, as exceeding the guideline may have significant health effects in some cases. More sampling provides a greater degree of protection.

The main disadvantage of this approach is that estimates of percentiles are inherently more uncertain than estimates of means.

Statistics – statistical principles

INFORMATION SHEET 3.2

Statistical advice should be sought in devising a sampling program; however, this sheet sets out some general principles and considerations.

When a mean or the 95th percentile is calculated or estimated from a given number of samples, the question arises, how accurately does the figure represent the true mean or 95th percentile? In order to answer this question, some basic statistical principles must be understood.

MEASUREMENT ERROR

A set of results is no more than a series of snapshots of some process over the period of sampling. A statistic calculated from these results, such as a percentile, a mean, or a standard deviation, can never exactly coincide with the true statistic, except by chance. The true statistic could only be determined by continuous error-free measurement of every drop of water – an impossibility in water quality analysis.

Values determined experimentally from a set of measurements are, thus, often referred to as estimates of the true statistic. These estimates may be too high or too low – there is no way of knowing. This uncertainty is known as the measurement error (although the term 'error' is unfortunate as it really means 'small departures from the true result', not mistakes made in analysis), and quantification of this error is the central purpose of statistical methods.

NORMAL AND SKEWED DISTRIBUTIONS

When analysing chemical or physical data, particularly large data sets, it is common to find that measurements are fairly evenly distributed about the mean, with most measurements very close to the mean (slightly below, slightly above, or at the mean), and progressively fewer measurements as one moves away from the mean. This type of distribution is called a normal distribution and, when plotted as a frequency distribution, forms a characteristic bell-shaped curve. The normal distribution has special significance in statistics, with a number of useful properties. It is symmetric about the mean, and is defined by only two parameters – the mean and the standard deviation. As a result, a number of simple statistical procedures have been developed to deal with data that follow a normal distribution.

If the data set is skewed, a higher proportion of the data will be on one side of the mean than the other, giving rise to an asymmetric distribution. From a statistical point of view, it is more difficult to deal with a skewed distribution. Fortunately, if the data set is large enough, it will usually approximate a normal distribution.

There are statistical tests that can be used to determine whether a set of data is approximately normal[5] and if in doubt, these tests should be applied. A simple check, however, is to compare the mean and the median (the median is the midpoint in the data, such that half the data are greater in magnitude than the median, and half are less). If the two are close, then the data are likely to be evenly distributed about the mean and probably follow a normal distribution. Transforming highly skewed data (e.g. by taking logarithms) can often be used to generate a pseudonormal data set that can then be analysed as if it were normal. If data are transformed prior to analysis then the reverse transformation must be applied to the calculated statistics.

5 – Sokal RR and Rohlf FJ (1969). ***Biometry.*** WH Freeman and Company, San Francisco.

CONFIDENCE INTERVALS

The uncertainty in the estimated percentile or mean can be measured by the confidence interval. The confidence interval specifies upper and lower limits, so that within a known probability, the interval covers the true percentile or true mean.

The confidence interval for a normal distribution can be calculated from the number of samples, the mean, and the standard deviation. A confidence interval for the mean, or the 95th percentile, is {z-D, z+D}, where z is the mean or the 95th percentile, and the term D is derived from the standard deviation and the number of results (D is known as the precision, and is equal to half the width of the confidence interval).

The formula used to calculate D is:

$$D = \frac{t(a) \times s \times h}{\sqrt{n}}$$

where:

h = an uncertainty factor in estimating percentiles: for the 95th percentile it is equal to 1.64; for the mean it is equal to 1

t(a) = Student's t statistic with (n–1) degrees of freedom corresponding to a single tail probability of *a* (or a confidence of 100 ((1–2a)%)

n = number of independent random samples

t(*a*), known as the Student's t statistic, is a mathematical function that is commonly used in statistics. If more than 20 results are available, it is common to use t(*a*) = 2 at the 95% confidence level. More precise values for the Student's t-statistic for different values of n, and for different degrees of confidence, are given in statistical tables.

For example, suppose that:

mean = 10

standard deviation = 5

number of results = 25

then:

$$D = \frac{2 \times 5}{\sqrt{n}} = 0.7$$

Hence, in this example, the 95% confidence interval for the mean is {10–2, 10+2} or {8, 12}. Another way of expressing this is to say that there is a 95% chance that the interval {8, 12} contains the true mean.

The 95th percentile can be estimated using the mean and the standard deviation (s):

95th percentile = mean + 1.64 x s

The confidence interval for the 95th percentile is calculated in the same way as given above.

It is important to note that, for a given probability (or degree of confidence), the confidence interval becomes narrower as the number of results increases (i.e. the more sample results available, the greater the confidence in the estimate of the mean or percentile). This is a function of the Student's t statistic (or the t(*a*) value), which becomes smaller as the number of results increases, and of the √n term in the denominator in the above equation.

***Box IS3.1** – Assessment of turbidity data*

Turbidity is a non-health related characteristic and consequently performance can be assessed using the mean value of results for the last 12 months. For the monthly data given below (turbidity in nephelometric turbidity units, or NTU):

1.8, 3.2, 1.4, 2.8, 2.6, 1.2, 1.5, 5.2, 3.2, 3.4, 3.4, 2.8

Mean = 2.7

Standard deviation = 1.1

t(a) = 2.2 for 12 results (which equals 11 degrees of freedom, i.e. n – 1)

Hence:

$$D = \frac{2.2 \times 1.1}{3.46} = 0.7$$

Therefore for the above data, performance can be quoted as follows:

Guideline value = 5 NTU

Mean = 2.7 ± 0.7 (with 95% confidence)

It could therefore be concluded that performance is satisfactory as the upper bound of the confidence interval (2.7 + 0.7 = 3.6) is below the guideline value.

***Box IS3.2** – Assessment of trihalomethane data*

Trihalomethanes (THMs) are health-related, and consequently performance can be assessed using the 95th percentile of results for the last 12 months. For the monthly data given below (THMs in mg/L):

0.295, 0.250, 0.209, 0.222, 0.214, 0.211, 0.138, 0.143, 0.087, 0.093, 0.090, 0.200

Mean = 0.180

Standard deviation = 0.068

95th percentile = mean + 1.64 x s

= 0.180 + 1.64 (0.068 = 0.290

t(a) = 2.2 for 12 results (which equals 11 degrees of freedom, i.e. n – 1)

Hence:

$$D = \frac{2.2 \times 0.068 \times 1.64}{3.46} = 0.07$$

Therefore for the THM data, performance can be quoted as follows:

Guideline value = 0.25 mg/L

95th percentile = 0.29 ± 0.07 (with 95% confidence)

It could therefore be concluded that performance is unsatisfactory as the upper bound of the confidence interval (0.29 + 0.07 = 0.36) is above the guideline value.

OUTLIERS AND 'LESS THAN' VALUES

Two persistent problems cause difficulties in the use of the mean in assessing water quality data. These are:

- Outliers; that is, numbers that appear to be extreme when compared with other data in the data set. These are not numbers generated by some malfunction of measuring equipment or transcription errors, which clearly ought to be discarded. They are numbers that seem anomalous, although there is no obvious explanation and they cannot be discarded on technical grounds.
- Values that are recorded as less than the limit of detection.

As an example, consider the following set of data:

< 0.5, < 0.5, 1.2, 1.4, 1.45, 2.1, 21.3

The first problem is what to do about the less-than values. Should they be ignored, replaced by 0.25, replaced by 0 or should the < symbol be ignored? There is no clear answer except that it can be shown that using L/2, where L is the limit of detection, is effectively a worst-case method and not the even-handed approach it appears to be at first sight.[6] If the values below the limit of detection are critical in determining how a supply performs against the guidelines, then steps should be taken to reduce the limit of detection. Statistical treatment of values below the detection limit is possible but is complex and not entirely satisfactory.

The second problem is the very high 21.3 value. Is it genuine, or an analytical error? If it is genuine, is it valid to include it in the calculation of the mean (and hence the 95th percentile) when it will clearly have a marked effect on the result? The answer is that it must be included in the calculation as it may have an impact on the health of people receiving the water. To remove it would have the same effect as censoring the data set. Only those data points that have been clearly shown to be in error should be removed.

6 – Ellis JC (1989). Handbook on the Design and Interpretation of Monitoring Programmes, Water Research Centre, Medmenham, United Kingdom, Technical Report NS29

Number of samples required

INFORMATION SHEET 3.3

NON-MICROBIAL

It is intuitively obvious that poor quality water supplies should be more frequently monitored than good quality water supplies; this is supported by statistical arguments as shown below.

Provided the data are distributed normally, the minimum number of samples required to achieve a desired level of precision with a known degree of confidence can be determined using the following formula:

$$n = \frac{\{t(a) \times h \times s\}^2}{D}$$

Where:

- t(a) = Student's t statistic with infinite degrees of freedom corresponding to a single tail probability of a: at the 95% confidence level this value is 1.96
- h = an uncertainty factor in estimating percentiles: for the 95th percentile the value is 1.64 (at the 95% confidence level): for means the value is 1.0
- s = standard deviation
- D = precision in measurement
- n = number of samples required.

If the data are skewed then it is still possible to calculate the number of samples required but the calculation is more complex.[7]

***Box IS3.3** – Samples required to meet a guideline based on a 95th percentile*

Suppose that in the past a characteristic has been running with a mean of 20 mg/L with a standard deviation of 20 mg/L, and that for this characteristic the guideline value is 100 mg/L. The 95th percentile can be estimated as follows:

$$\text{95th percentile} = \text{mean} + 1.64 \times s = 20 + 1.64 \times 20 = 52$$

This is well below the guideline value. It would be possible to take fewer samples and still be confident that the guideline has been met.

To estimate the minimum number of samples necessary, the first step is to calculate the necessary precision (calculated as D in Information Sheet 3.2) by halving the difference between the 95th percentile and the guideline value:

$$\frac{(100–52)}{2} = 24 \text{ mg/L}$$

The lower limit of the confidence interval is the estimated 95th percentile, and the upper limit is the guideline value. The number of samples required to achieve this can then be calculated as follows:

$$n = \frac{\{1.96 \times 1.64 \times 20\}^2}{2} = 8 \text{ with rounding up}$$

Thus, a precision of 24 mg/L can be achieved (with 95% confidence) by taking 8 samples over the year. Alternatively, 8 samples per year will be sufficient to be sure (with 95% confidence), that the 95th percentile is less than the guideline value.

7 – Ellis JC (1989). Handbook on the Design and Interpretation of Monitoring Programmes, Water Research Centre, Medmenham, United Kingdom, Technical Report NS29

***Box IS3.4** – Samples required to meet guidelines based on 95th percentile, with a different mean*

Suppose that after taking these 8 samples it is found that the mean has drifted up to 40 mg/L but the standard deviation remains the same at 20 mg/L. The 95th percentile is now:

95th percentile = mean + 1.64 x s = 40 + 1.64 x 20 = 72

The precision now required is 14 mg/L (as 100–72/2=14 mg/L). This is a smaller value and hence the number of samples required to achieve it with the same degree of confidence will increase. In fact:

$$n = \frac{\{1.96 \times 1.64 \times 20\}}{14} = 22$$

Thus, the sampling frequency would have to be increased to 22 per year, or about 1 per fortnight, to meet this change in precision.

Box IS3.5 – Number of samples based on meeting a mean

Using the same data given in Example 2 above, the precision required can be calculated by halving the difference between the mean and the guideline value, i.e. (100–40)/2 = 30 mg/L. (The lower limit of the confidence interval in this example is the mean, and the upper limit is the guideline value). The number of samples required is then:

$$n = \frac{\{1.96 \times 20\}^2}{30} = 2 \text{ with rounding up}$$

Thus, 2 samples per year would be sufficient to be sure (with 95% confidence) that the mean is less than the guideline value. Using a mean instead of a 95th percentile can make a substantial difference to the number of samples required.

MICROBIAL

One of the aims in any sampling program, particularly microbiological sampling, is to have a high degree of confidence that the water quality as measured in the laboratory is representative of that actually used by the consumer, not just at the time of sampling, but all the time. Unless all water is sampled, it is not possible to be 100% confident that this condition is met. A properly designed sampling program, testing only a very small percentage of the total amount of water in a system, can give a high degree of confidence about the overall water quality. The degree of confidence is related to the number of samples analysed. (This assumes, of course, that the sampling locations selected are representative of the water supplied to the consumer.)

Even if all samples tested are free of bacterial indicators, no sampling program can guarantee that *all* the water in a system is free of indicator organisms. In fact it can be shown that for any reasonable sampling program, the degree of confidence in achieving a situation where 100% of the water in a system is free of bacterial contamination is close to zero (Ellis 1989).

It is far better to have a high degree of confidence that a large proportion of the water is free of contamination, than to have no confidence that all the water is uncontaminated. Realistic monitoring programs can give a high degree of confidence that 98% of all the water in a system is free of bacterial contamination.

This does *not* mean that the other 2% of water is contaminated. All it indicates is that the sampling program is statistically unable to show a high degree of confidence that more than 98% of all the water in the system is free of contamination.

Even if all samples tested are uncontaminated it does not follow that there is necessarily a high degree of confidence that the water is free from contamination. The number of samples required to meet the 98% compliance requirement, and the degree of confidence that this confers when all samples are free of contamination is shown in Figure 1 (Ellis 1989).

For example, if 50 samples are tested per year and all are free of contamination, then there is only 65% confidence that 98% of the water in the system is free of contamination. It would be necessary to take 150 samples, each free of contamination, before the degree of confidence reached 95%. Fewer than 50 samples per year, even if each sample was free of contamination, give a low degree of confidence that the water system as a whole is 98% free of contamination.

If one or more samples taken over a year are positive, then the degree of confidence that 98% of water in the system is free of contamination is reduced. This is shown in Figure 2 (Ellis 1989). Suppose, for example, that 150 samples were collected in a year but some of those samples showed faecal contamination. The degree of confidence that 98% of the water in the system is free of contamination drops from 95% with a positive result to 80% with one positive result, and 60% with two positive results.

The plateau shown in Figure 2 at the 50% confidence level is an artefact of the difficult computation procedure used to derive these graphs. The graphs should only be regarded as an approximate guide, but they nevertheless provide a highly informative summary.

REFERENCE

Ellis JC (1989) Handbook on the design and interpretation of monitoring programmes.
Water Research Centre, Medmenham, UK, Report NS No 29.

Figure 1

The curve shows the level of confidence that 98% of water in a supply is free of faecal contamination for different numbers of samples when all samples tested are free of faecal contamination (from Ellis 1989, reprinted with permission of the Water Research Centre, Medmenham).

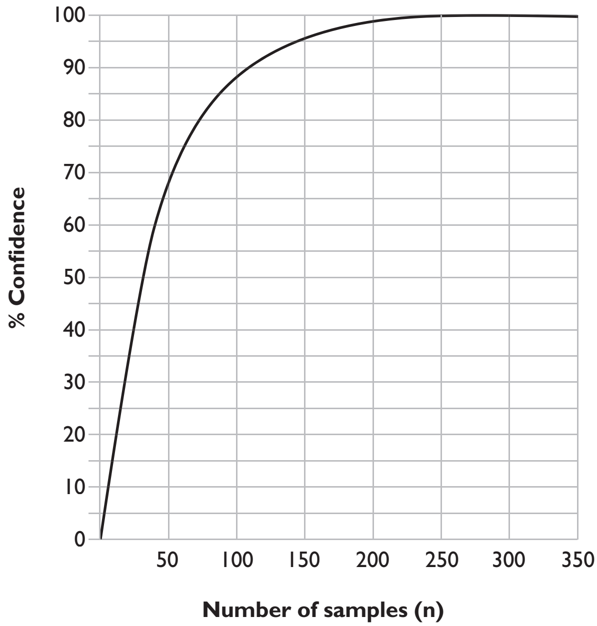
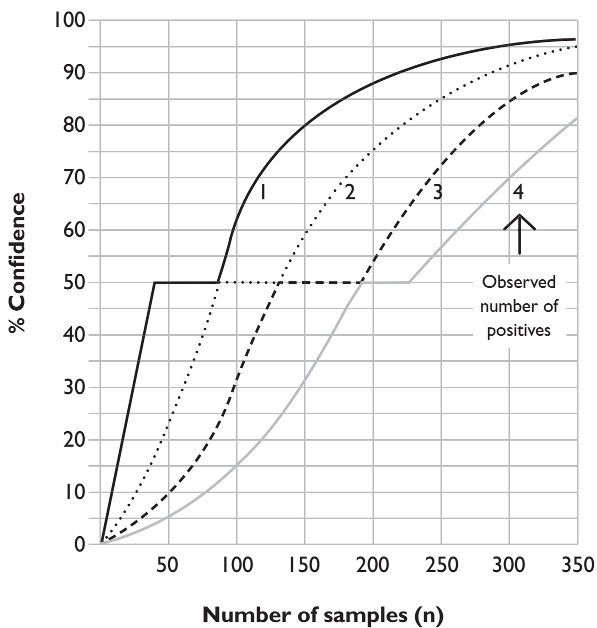


Figure 2

The curves shows the level of confidence that 98% of the water in a supply is free of faecal contamination for different numbers of samples when 1, 2, 3 or 4 samples give positive results (from Ellis; 1989, reprinted with permission of the Water Research Centre, Medmenham).



Statistics – control charts

INFORMATION SHEET 3.4

PURPOSE AND CONTENTS OF A CONTROL CHART

A control chart displays monitoring data for a given characteristic against either time or sample sequence number.[8] It has the following important features clearly marked:

- the guideline value
- each measured data point
- the mean value of the measurements
- control limits.

PURPOSE OF CONTROL LIMITS

Control limits are based on long-term monitoring data (including data from the reporting period). They are horizontal lines parallel to the mean but shifted from it by a number of standard deviations (at least 1.64), and they are calculated from the long-term standard deviation. They thus define the area within which most of the long-term data fall. Provided that the system is 'in control', most of the data for the reporting period will also lie between these limits.

Control charts can also be used to assess performance on an ongoing basis (rather than for a given reporting period), in which case the control limits and mean should be calculated from all the available data over previous years, and recalculated periodically (see figure 3).

ADVANTAGES OF USING CONTROL CHARTS TO ASSESS PERFORMANCE

There are a number of advantages in using control charts to assess performance:

- It is easy to see if data exceed the guideline value, and by what amount. A number of small excursions above the guideline value spaced well apart in time may be of less concern than one very high value or a number of closely spaced excursions.
- The difference between the mean and the guideline value can be easily seen. For some characteristics, what is critical is the total amount accumulated over a lifetime. Where the mean value for such characteristics is well below the guideline value, there may be no cause for concern, even if some individual measurements are well above the guideline. Such a pattern is clearly visible on a control chart.
- The variability in the data can be quickly determined. Characteristics with a low variability may be of less concern than those that vary markedly. Trends in the data may also be significant.
- The difference between the upper control limit, the guideline value and the mean provide a useful guide as to the likelihood that the guideline value will be exceeded at some time. If the upper control limit is well below the guideline value and close to the mean, it is unlikely that the guideline value will be exceeded. If, on the other hand, the upper control limit is close to the guideline value and distant from the mean, the guideline value is more likely to be exceeded. This can be a useful way of determining the key characteristics for monitoring.

8 – APHA Method 1010B (1992). General Introduction: Statistics, Standard Methods for the Examination of Water and Wastewater, 18th Edition. American Public Health Association, Washington, United states

SETTING CONTROL LIMITS

A decision must be made on where to place the control limits; that is, on the percentage of the long-term measured data that they will contain (see table below). The greater this percentage, and the further the upper control limit is below the guideline value, the greater the confidence that the guideline value will not be exceeded in the periods between measurements, and that the quality of the water will be regarded as good. It is suggested that the control limits should be not less than 1.64 times the long-term standard deviation: this will encompass approximately 90% of the long-term data and, provided the system remains in control, approximately 90% of the data for the reporting period. The distances for other percentages of the data are shown below. These figures are constants for any normal distribution curve, and can be determined from cumulative normal probability tables given in most statistical textbooks.

Table IS3.1 *Relationship between control limits and multiples of the standard deviation*[9]

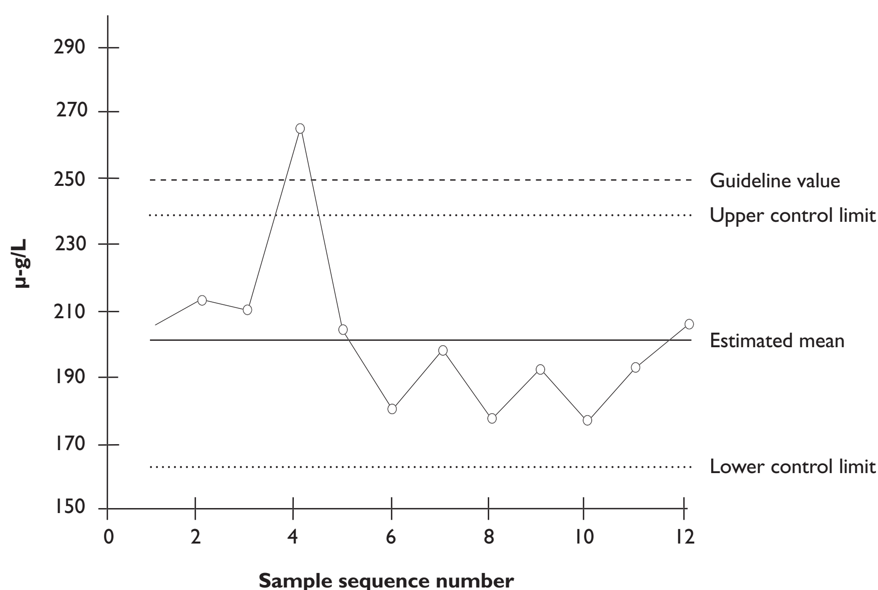
Standard deviations(s)	% of data expected to fall within the bounds
1.64 x s	90.00
1.96 x s	95.00
3.00 x s	99.85

DETERMINING THE STANDARD DEVIATION

In order to establish control limits, it is necessary to determine a reliable mean and long-term standard deviation. To obtain initial estimates of these statistics, no less than 7 and preferably 15 or more measurements are required from independent representative samples. It is clearly unsatisfactory to bias the results by selecting sampling times or locations that are favourable (or unfavourable).

Figure 3

An example of a control chart for trihalomethane data using 12 monthly measurements. The control limits have been placed at two standard deviations away from the mean.



9 – Taylor JK (1987). ***Quality assurance of chemical measurements***, Lewis Publishers, Chelsea, Michigan