# The distribution system

Contents

16.1 Introduction 2

16.1.1 Critical points in a distribution system 3

16.2 Components of a distribution system 5

16.2.1 Service reservoirs 6

16.2.2 Distribution network 7

16.2.3 Pump stations 8

16.2.4 System monitoring and control 8

16.2.5 Design issues affecting water quality 9

16.2.6 Permeation, leaching, intrusion and pressure drop 11

16.3 Operations and maintenance 18

16.3.1 Service reservoir operation 18

16.3.2 Reticulation operation 20

16.3.3 Maintenance of disinfection residual 29

16.3.4 Barriers against recontamination during maintenance 30

16.4 Aesthetic considerations 35

16.4.1 Wholesomeness 35

16.4.2 Consumer complaints 40

References 41

List of figures

Figure 16.1: Typical reticulation system 4

Figure 16.2: Reservoir short-circuiting: severe (left) vs moderate short-circuiting 7

Figure 16.3: Fire hydrant standpipe being used to flush a water main 22

Figure 16.4: Commissioning a backflow prevention device 24

Figure 16.5: Example of corroded water pipe 37

Figure 16.6: Structure of a biofilm 40

## Introduction

The introduction in WHO (Water Safety in Distribution Systems 2014) includes:

The integrity of well managed distribution systems is one of the most important barriers that protect drinking-water from contamination. However, management of distribution systems often receives too little attention. Distribution systems can incorrectly be viewed as passive systems with the only requirement being to transport drinking-water from the outlets of treatment plants to consumers.

There is extensive evidence that inadequate management of drinking-water distribution systems has led to outbreaks of illness in both developed and developing countries. The causes of these outbreaks and the range of chemical and microbial hazards involved are diverse. Between 1981 and 2010 in the USA, 57 outbreaks were associated with distribution system faults, leading to 9,000 cases of illness. The most common faults were cross-connections and back-siphonage; other faults included burst or leaking water mains, contamination during storage, poor practices during water main repair and installation of new water mains, pressure fluctuations and leaching from pipework; a significant proportion of faults are unknown. Elsewhere, outbreaks of illness have been associated with low water pressure and intermittent supply.

The most common causes of illness were enteric pathogens, including bacteria (*Salmonella*, *Campylobacter*, *Shigella*, *Escherichia coli* O157), protozoa (*Cryptosporidium*, *Giardia*) and viruses (norovirus). Chemicals, including copper, chlorine and lead, were associated with eight outbreaks (14 percent).

Outbreaks are the most noticeable outcome of distribution system failures, but represent only a small fraction of contamination events. Cross-connections, leaks and water main breaks and transient low water pressures are common events; although most do not cause reported outbreaks, it is likely that some could cause sporadic cases of illness that go undetected.

The transmission of water from the source or water treatment plant to the various consumers is usually done in two stages, distribution and reticulation. The former term is generally used to describe the system of bigger (or trunk) mains, reservoirs and, in some situations, pumping systems. In bigger systems such as in cities, the distribution function is well-defined and often operated separately. In large systems or where water is delivered to separate water suppliers, the initial delivery can be through bulk or trunk mains. The term reticulation is normally used to describe the street mains and connections to properties. However, use of these terms does tend to be interchangeable.

The distribution system is designed to:

* reliably distribute bulk water supplies to the suburbs, or supply points
* provide water at the correct elevation and/or pressure
* buffer the diurnal peaks in demand from the consumers
* maintain the water quality.

To achieve these objectives, particular combinations of reservoir storage, ring mains and pumping arrangements are used, depending upon the system topography and size.

A distribution system may also be made up of distribution zones. A distribution zone is a part of the distribution system in which all consumers receive drinking-water of identical quality, from the same or similar sources, with the same treatment and usually at the same pressure and is usually clearly separated from other parts of the network, generally by location, but in some cases by the layout or composition of the pipe network. In these Guidelines the term distribution system is used to include specific zones.

### Critical points in a distribution system

Critical points are those points where procedures for equipment failure would lead to a public health hazard. Specific critical points are discussed in this chapter to highlight and differentiate the types of risk that are present in a distribution system. There are two types of critical points in the distribution system, those critical to continuity of supply and those critical to water contamination.

Water contamination is an obvious and direct risk to public health. It can occur directly by intrusion of contaminants into the system or by chemical reactions within the system (such as chemical reactions with the pipe structure). The contamination of water within the distribution system is discussed in detail in this chapter. Procedures for dealing with mains installation and repair are discussed in section 16.3.4.

Supply loss is also a critical point for public health, but is not the subject of these Guidelines. For the initial time (say several hours), the risks to the community are not those of thirst, they are those of fire fighting, minimal interruptions to industry, inadequacy of water for flushing away sewage, and for personal hygiene. The factors that could lead to supply loss include:

* loss of source water supply
* treatment failure
* water main failure
* service reservoir valve operation: inlet fails to open, drain fails to close
* water contamination, meaning supply must be stopped.

Emergency storage is required in order to continue supply when the inlet main is broken, during upstream system maintenance, or during some other loss of supply situation.

In practice, most supply losses involve a dual failure: a mechanical/electrical defect or human error that occurs **and** an alarm system that fails to provide warning in time to take corrective action. Therefore the alarm system needs regular testing and valves need regular working and testing, and staff needs regular training. Situations that can lead to loss of supply should be addressed in the water safety plan (WSP – formerly known as a public health risk management plan, PHRMP) or other appropriate manual.

Figure 16.1: Typical reticulation system



Risk management issues related to the distribution system are discussed in the:

* MoH Public Health Risk Management Plan Guide PHRMP Ref: P2: [Treatment Processes – Water Transmission](http://www.moh.govt.nz/moh.nsf/0/5AF58E090CF4098BCC25699600754798/%24File/WaterTransmissionV1.doc). Ministry of Health, Wellington.
* MoH Public Health Risk Management Plan Guide PHRMP Ref: P10: Treatment Processes – Pump Operation. Ministry of Health, Wellington.
* MoH Public Health Risk Management Plan Guide PHRMP Ref: D1: Distribution System – Post-Treatment Storage. Ministry of Health, Wellington.
* MoH Public Health Risk Management Plan Guide PHRMP Ref: D2.1: Distribution System – Construction Materials. Ministry of Health, Wellington.
* MoH Public Health Risk Management Plan Guide PHRMP Ref: D2.2: Distribution System – System Pressure. Ministry of Health, Wellington.
* MoH Public Health Risk Management Plan Guide PHRMP Ref: D2.3: Distribution System – Operation. Ministry of Health, Wellington.
* MoH Public Health Risk Management Plan Guide PHRMP Ref: D2.4: Distribution System – Backflow Prevention. Ministry of Health, Wellington.

WHO (2004) produced an excellent publication entitled *Safe Piped Water: Managing Microbial Water Quality in Distribution Systems*. This publication is available on the internet at <http://www.who.int/water_sanitation_health/dwq/924156251X/en/> and then select the chapter. The chapters are titled:

* [Contents, foreword, acknowledgements, acronyms and abbreviations [pdf 132kb]](http://www.who.int/entity/water_sanitation_health/dwq/en/pipedtoc.pdf)
* [The microbiology of piped distribution systems and public health [pdf 119kb]](http://www.who.int/entity/water_sanitation_health/dwq/en/piped1.pdf)
* [Minimising potential for changes in microbial quality of treated water [pdf 256kb]](http://www.who.int/entity/water_sanitation_health/dwq/en/piped2.pdf)
* [Design and operation of distribution networks [pdf 157kb]](http://www.who.int/entity/water_sanitation_health/dwq/en/piped3.pdf)
* [Maintenance and survey of distribution systems [pdf 119kb]](http://www.who.int/entity/water_sanitation_health/dwq/en/piped4.pdf)
* [Precautions during construction and repairs [pdf 88kb]](http://www.who.int/entity/water_sanitation_health/dwq/en/piped5.pdf)
* [Small animals in drinking-water distribution systems [pdf 291kb]](http://www.who.int/entity/water_sanitation_health/dwq/en/piped6.pdf)
* [Risk management for distribution systems [pdf 182kb]](http://www.who.int/entity/water_sanitation_health/dwq/en/piped7.pdf)
* [Index [pdf 56kb]](http://www.who.int/entity/water_sanitation_health/dwq/en/pipedindex.pdf).

USEPA (2006a) discusses in some detail several indicators and procedures that may be useful for assessing the quality of drinking water within potable water distribution systems. USEPA (2006b) discusses inorganic contamination in potable water distribution systems.

Water UK (2010) includes seven Technical Guidance Notes related to issues concerning the distribution system.

WHO (2011b) discusses issues related to water quality in buildings.

See <http://www.awwa.org/files/Resources/Standards/StandardsSpreadsheet.xls> for a list of AWWA Standards, many of which cover aspects of distribution systems. They have a large range of technical manuals covering distribution practices too (www.awwa.org).

## Components of a distribution system

The general components of a water distribution system and their influence on water quality are described in this section. A more detailed description of the components themselves can be found in other Ministry of Health resources such as the Water Assessor Training Notes, which are available online. The AWWA (USA) has prepared manuals on various aspects of the distribution system (see references). Effective operation of the components to maintain water quality is discussed in Chapter 16.3.

### Service reservoirs

A water reservoir or tank is normally a structure that allows a different inflow and outflow at any given time. When inflow is less than outflow, water is being drawn from storage. Peak attenuation storage allows the treatment plant to produce water at more consistent treatment rates, thereby enhancing treatment performance; it also reduces the cost of building or upgrading a water treatment plant (Beca 2010). Some reservoirs or tanks have a common inlet/outlet. Unless the reservoir volume is small in relation to the water flows, this is not good design because it can lead to stale water accumulating on the far side.

Important entry points to a reservoir for contaminants include wildlife access and human access. Reservoirs should also be designed to keep the water fresh and to prevent the carry-over of sediment. Features designed to maintain water cleanliness include:

* reservoirs must have a secure lid and manhole covers designed to prevent surface runoff entering
* controls against non-authorised people gaining access. These may consist of security fences, locked manhole covers, and/or architectural constraints (tall walls with no footing/grips). Non-authorised access falls into two groups: casual/curious, and malicious. The former include children and casual passers-by; the latter may include vandals and, rarely but possibly, active saboteurs
* constraints against environmental vectors. Reservoirs are required to allow air in and out as the water level changes so they must be ventilated to the atmosphere. However, the ingress of small animals, birds and mosquitoes should be prevented. Wind carried debris and fumes should be excluded, as should surface or underground natural water which may carry contaminants. Buried tanks present a potential problem if the water table is higher than the reservoir water level. If a buried reservoir is grassed, animals should not be allowed to graze above the roof
* timber tanks should have an impermeable liner beneath the roof
* circulation systems should be built into reservoirs. There is a natural tendency for water to rotate due to the spin of the earth but this should not be relied upon to stir and mix inflows. If the reservoir does not have internal partition walls to encourage plug flow, the inlets should be sited on the far side to the outlets, and the inlets should discharge at an angle to promote circulation, see Figure 16.2. Inlets are often placed above the water surface to provide an air gap to avert back flows. Outlets are obviously placed near the bottom
* the outlet should be designed to avoid picking up any sediment that may settle out in the reservoir
* if the outlet for draining the reservoir discharges to a sewer or stormwater system, an air gap or other suitable backflow prevention must be provided
* water sampling provisions should be incorporated in the early design phase.

Figure 19.2 in Chapter 19: Small and Individual Supplies shows some design features aimed to prevent contamination of a water tank. These features apply to service reservoirs too.

Figure 16.2: Reservoir short-circuiting: severe (left) vs moderate short-circuiting



### Distribution network

Water mains are broken down into a number of categories based on function:

* trunk mains: are those that connect treatment plants to reservoirs and, in some instances, reservoirs to demand areas. They are likely to have control valves and can often be taken out of service for several hours without interrupting general supply. Trunk mains rarely have customer connections and often do not have fire hydrants
* reticulation mains: are used to supply consumers directly and thus have service connections made to them. They are usually fitted with fire hydrants at about 135 m spacing. Reticulation mains may be supplied from reticulation (or service) reservoirs or, in some systems, by control valves (often pressure reducing) from trunk mains
* service connections: are where customers connect to the main. They fall into three categories: household services, multiple/commercial/industrial services and fire services.

One of the important factors influencing water quality is the effect of the various materials that come into contact with the water (see section 16.2.6). The potential effect becomes more critical as the size of the system decreases from reticulation to plumbing systems, and the residence time in contact with these systems increases. AS/NZ Standard 4020 (2002) provides a means to test such materials in order that achieving the appropriate national recommended water quality values are not jeopardised. Materials used in potable waters should comply with AS/NZS 4020, and coatings and jointing compounds should be applied and cured correctly. In the UK there is a list of products and processes that have been approved for use in their water supplies following testing (under DWI 2011). Information is also available by contacting NSF (see references). For example, NSF/ANSI Standard 61: Drinking Water System Components – Health Effects, whichcontains procedures to evaluate products that come into contact with drinking-water and to screen out those which might contribute excessive levels of contaminants into drinking-water.

Water distribution system materials are required to have corrosion resistance to the water inside them, not only so they do not collapse, but so that problematic materials don’t pass into the water. This is discussed further in section 16.4.

Materials must also be resistant to adverse ground chemistry, the aggressiveness of the supply, and to breakages. A poor choice of materials can lead to deterioration in water quality as well as increased maintenance and early replacement.

Some pollutants such as hydrocarbons and phenols may diffuse through some plastic piping materials so attention should be given to the location of water mains in some cases. Intrusion is most likely to appear as a taste and odour issue (see section 16.2.6).

### Pump stations

A pump station is installed where water must be lifted from a low level to a high level. The flow may also be pressurised to a higher hydraulic grade instead of installing a high level reservoir. Virtually all pumps used to lift water more than a few metres are centrifugal pumps.

Most pump sets comprise two pumps: one set to duty and the other on standby. This arrangement means that if the duty pump fails to start, the standby can be used to avoid production loss. To avoid accumulation of very old water in the standby system, the allocation of the duty and standby pumps should be alternated from time to time. This will also ensure that the standby pump remains functional and will spread the wear over both (or all) pump sets. Where possible, pumps should start up slowly to reduce the scouring effect of a sudden increase in water velocity that may lead to dirty water.

The lubricant used in water supply pumps should be suited to the application. Where there is any risk of contamination of the water supply, an oil designed for potable applications should be considered. There is no New Zealand standard for lubricants for use in potable applications. As a guide the lubricant should be listed under the New Zealand MAF Food Assurance Authority C15 or the United State Department of Agriculture Category H-1.

### System monitoring and control

SCADA (Supervisory, Control and Data Acquisition) systems are installed on many distribution systems to monitor and control the operation of the system. Chapter 17 provides further details on how these systems work.

Typical monitoring of a water reticulation system will include:

* reservoir levels
* pump operation
* system flows at key points (perhaps into and out of reservoirs)
* system pressure
* alarm systems set to warn when action is required
* online monitoring of free available chlorine (FAC).

A key requirement of monitoring is to set operator notification limits, there is no point in recording that a system is failing if no alarm rings! The limits, and actions to be followed when reached, need to be specified in the WSP.

SCADA provides a powerful tool for checking on design information and how well a section of the system is working. For example, monitoring how full a reservoir is and how often the pump starts/stops may reveal that the storage is too small or that the on/off probes are set too close together.

Instruments used in the distribution system

**Flow metering:** metering in the reticulation can occur at several locations for different reasons. Reservoir outflow meters, or meters on large primary distribution mains are used to monitor the total demand over a significant area. They are usually installed as part of the system management concerned with supplying and treating enough water. Individual property meters are small and must detect all the water drawn by the customer.

**Pressure:** proper water line pressure ensures enough supply for customers and for fire fighting, while protecting treated water from ingress of untreated groundwater. For this reason pressure is usually measured at strategic points in the distribution system.

**Level:** is measured in reservoirs as a part of a level control system and to activate alarms if the water level strays beyond acceptable bounds.

**Free Available Chlorine (FAC):** is measured in the network to ensure that a residual is maintained under all flow conditions.

### Design issues affecting water quality

Regulations covering design

Design of the distribution system should comply with current legislation for the protection of the quality of water. This is covered by the Health Act 1956 and the Health (Drinking Water) Amendment Act 2007 (HDWAA), and by the Building Act 1991 (BA).

The First Schedule of the Building Regulations made under the BA is the New Zealand Building Code (NZBC). A building with a water supply designed to AS/NZS 3500 (2003) will meet the requirements of the Building Code. AS3500.1: Plumbing and Drainage. Part 1: Water Services is called up as a verification method in the New Zealand Building Code Clause G12/AS1, and this method includes individual protection, zone protection, and containment protection. Containment protection will meet the requirements of the water supplier if a backflow preventer is installed at the boundary (also see 69ZZZ of HDWAA).

Installation

Poor workmanship is a principal cause of water main failure and recontamination. It is important to liaise with the personnel responsible for the laying and maintenance of the distribution system to minimise any likely sources of contamination due to defective installation methods. This includes ensuring that pipes are cleaned and the ends covered while in storage and being laid. This is described more fully in section 16.3.2.

Service reservoirs

Common inlet/outlet pipes are not recommended because they tend to allow water to become stale. Inclusion of baffle or partition walls will help reduce short-circuiting. Collection of samples for *E. coli* testing through manholes may lead to contamination, so including sample taps at the design stage is advisable. Also refer to section 16.2.1.

Reticulation

Dead end pipes are not recommended. In areas that experience persistent dirty water, it may be possible to join dead end pipes by using right-of-ways.

Choice of materials

Water can corrode metallic materials. The composition of the water determines the rate of corrosion. Corrosion can damage the asset and contaminate the water. The principal corrosion contaminants may include aluminium, antimony, arsenic, bismuth, cadmium, copper, iron, lead, nickel, organolead, organotin, selenium, tin, and zinc.

Lead may leach into potable water from lead pipes in old water mains, lead service lines, lead in pipe jointing compounds and soldered joints, lead in brass and bronze plumbing fittings, and lead in goosenecks, valve parts or gaskets used in water treatment plants or distribution mains. DWI (2016) conducted a study into lead leaching from the introduction of water meters, concluding that installation of meters or other fittings into lead pipes can lead to transient increases in lead concentration in the water. These elevated concentrations, mainly of particulate lead, can last for about three days and can be effectively removed by flushing.

Copper is used in pipes and copper alloys found in domestic plumbing. Copper alloys used in potable water systems are brasses (in domestic fittings) and gunmetals (in domestic plumbing valves). Brasses are basically alloys of copper and zinc, with other minor constituents such as lead and arsenic. Brass fittings are also often coated with a chromium-nickel compound. Gunmetals are alloys of copper, tin and zinc, with or without lead.

Galvanised pipes will release zinc, since they are manufactured by dipping steel pipes in a bath of molten zinc. Galvanised pipes can also be sources of cadmium and lead, since these materials are present as impurities. When the zinc has gone the steel corrodes.

Corrosion is discussed in several sections of Chapter 10. It is also covered in Health Canada (2009).

DWI (2016) summarises research into improving the understanding of the long term leaching behaviour of lead and nickel from the brass fittings. Overall project conclusions were:

* brass fittings can cause compliance failures for lead and nickel after initially being installed but leaching of these metals diminishes dramatically by 30 days in service with the flushing protocols used in this research
* all low lead fittings tested showed significantly less lead and nickel leaching compared with their leaded brass counterparts
* neither seasonal, nor stagnation temperatures, appeared to contribute significantly to the leaching for the metals of interest in the project
* phosphate dosing is effective and considerably reduces the leaching of lead and nickel from the brass fittings tested
* when phosphate dosing is stopped there is a short-lived period, of less than a day, prior to leaching commencing once more
* the yields from combinations of several brass fittings (“under the sink” and “in the road”) are capable of causing lead and nickel compliance failures in certain circumstances, significantly contributing to their concentration in water
* the use of low lead brass fittings would reduce the likelihood of currently sold brass fittings contributing significantly to the compliance of UK households
* other metals of interest such as copper, zinc, aluminium, manganese and cadmium did not cause compliance failures, from either individual or cumulative test fittings
* phosphate dosing can also suppress the leaching of zinc and copper in both hard and soft water.

### Permeation, leaching, intrusion and pressure drop

Water quality can be affected by the types of materials used in the distribution system and for the plumbing, and on the design and condition. Water quality can also be affected by the nature of the ground in which the pipes are buried, or by substances discharged to the soil. ANSI/AWWA have produced Standards for a wide variety of pipe types, fittings, tanks and water meters.

Permeation is a phenomenon in which contaminants migrate through the pipe wall into the water. Three stages are involved in physico-chemical process of permeation:

a) organic chemicals present in the soil partition between the soil and plastic wall

b) the chemicals diffuse through the pipe wall

c) the chemicals partition between the pipe wall and the water inside the pipe (Kleiner 1998).

Leaching is the process whereby chemicals enter the water supply from the materials used in the distribution system and plumbing, other than by corrosion processes. The AFNOR XP P41 250, EN 1420-1 and BS 6920-2.2.1 are migration/leaching testing standards used in France, Europe, and Britain respectively. All products used for the transport of water intended for human consumption are meant to be subject to these testing standards. Pre-testing and certification of materials does not always guarantee that taste and odour problems caused by leaching of organic compounds will not occur. Significant problems may also arise from improper installation of approved materials.

Intrusion occurs when contaminants are drawn into the pipework through holes.

a) Permeation

Permeation can occur either from the vapour or aqueous phase. With respect to potable water mains, the contaminants of interest include highly volatile hydrocarbons and organic solvents. Therefore, both water mains and fittings installed in the vadose and saturated zones are susceptible to contamination by permeation. Thermodynamic theory indicates that hydrostatic pressure within the pipeline provides negligible resistance to permeation at the pressure range commonly found in the distribution system.

More than 100 incidents of drinking-water contamination resulting from permeation of subsurface mains and fittings have been reported in just the United States (Glaza and Park 1992). The majority of these incidents were associated with gross soil contamination in the area surrounding the pipe. The occurrence of permeation incidents was equally split between high risk locations such as: industrial areas; former sites of fuel stations; near underground storage tanks; and low-risk locations such as residential areas. The sources of contamination for the low-risk areas included disposal and accidental leaking of gasoline, diesel fuel, oil, paint thinner products or solvents, Holsen et al (1991). A property next to a service station in Mt Albert, Auckland, experienced bad tastes and odours in their drinking-water in the early 1980s.

Pipes composed of polymeric materials (ie, plastics) were involved in 98 percent of the US incidents. The materials included polybutylene, polyethylene, polyvinyl chloride (PVC), and acrylonitrile-butadiene-styrene (ABS). No reported incidents of permeation through metal-based pipe were identified.

The contaminants most likely to permeate plastic are lipophilic and non-polar in nature. Diesel and petroleum products (mainly benzene and ethylbenzene) were involved in 89 percent of the incidents, while volatile chlorinated solvents accounted for 5 percent of the incidents. Other contaminants that exhibited high rates of permeation included (simple) chlorinated aromatics, chlorinated and unchlorinated straight-chain aliphatic hydrocarbons, and phenolic compounds. The taste or odour of ethylbenzene and xylenes are detectable before they reach concentrations of health concern; however, for most other chemicals that permeate the pipes, the opposite applies.

New PVC pipes exhibit lower permeation rates than new polyethylene or polybutylene pipes, primarily due to differences in the material matrices. PVC is an amorphous glassy polymer, while polyethylene and polybutylene are semi-crystalline rubber. At low solute activities, PVC is virtually impermeable. However, when exposed to high activity (eg, saturated) organic conditions, such as those that would occur during gross chemical spillage, PVC pipe can be softened to the point of failure.

WHO (2014) includes some interesting examples of permeation in Appendix 10.

b) Leaching

ANSI/NSF Standard 61: *Drinking Water System Components – Health Effects* establishes minimum health effects requirements for the chemical contaminants and impurities that are indirectly imparted (via leaching) to drinking-water from products, components, and materials used in drinking-water systems.

Tomboulian et al (2004) listed the chemicals found by NSF to have leached from various water system components into the water, as below. Datasheets have been prepared for many of these compounds.

##### Cement/concrete pipes/lining

2,4,6-tribromoanisole; 2,4,6-tribromophenol (Bromol); 2,4,6-trichloroanisole (Tyrene); 2,4,6‑trichlorophenol; antimony; calcium carbonate; calcium sulphate; chromium; diethanolamine; diethylene glycol; dioxin (TCDD); cipropylene glycol; dipropylene glycol‑*t‑*butyl ether; furan; iron oxide; magnesium oxide; melamine-sulfonate; naphthalene-sulfonate; *o*-phenylphenol; phenoxypropanol; tetracalcium trialuminumosulfate; tetraethyl diphosphate; triethanolamine; vanillin.

##### PVC/CPVC pipes

1,3-butadiene; antimony; calcium carbonate; calcium stearate; carbon black; chlorophenol; cyclohexanone; dibutyltin; diethylhexylphthalate; disononyl phthalate; ethyl acrylate; formaldehyde; monobutyltin; paraffin wax; polyethylene wax; titanium dioxide; tributyltin; vinyl chloride.

##### Polyethylene, HDPE, PEX pipes/lining

acetophenone; 2,4-bis (dimethylethyl)phenol; benzene; benzothiazole; bis‑(dimethylethyl)benzene; bisphenol A; BHT (methyl di(t-butyl)phenol); carbon disulphide; cyclohexadienedione; cyclo-hexanone; cyclopentanone; diazadiketocyclo-tetradecane; dicyclopentylone; dimethylhexanediol; di-*t*-butyl oxaspirodecadienedione; hydroxymethylethylphenyl ethanone; isobutylene; methanol; methyl butenal; methyl di-*t*-butyl hydroxyphenyl proprionate; methyl (di-*t*-butylhydroxy-phenyl)propionate; methylbutenol; nonylcyclopropane; phenolics; phenylenebis-ethanone; propenyloxymethyl oxirane; *t*-butanol; tetrahydrofuran; trichloroethylene. Skjevrak et al (2003) found 2,4-di-tert-butylphenol (2,4‑DTBP) which is a known degradation product from antioxidants used in HDPE pipes.

They also identified a range of esters, aldehydes, ketones, aromatic hydrocarbons and terpenoids leaching from HDPE pipes, the main ones being methyl and ethyl tertiary-butyl ether. Durand and Dietrich (2007) identified 2-ethoxy-2-methylpropane leaching from PEX pipes at 0.02 to >0.1 mg/L; panellists were able to smell the chemical at 0.005 mg/L.

##### Polyurethane coatings and liners, flexible fabric-reinforced polyurethane piping

1,4-butanediol; 4,4-methylenedianiline; bis(2-ethylhexyl) phthalate; bisphenol A diglycidyl ether; butyl benzyl phthalate; diphenyl(ethyl)phosphine oxide; di-*t*-butyl methoxyphenol; ethylhexanol; tetramethyl piperidinone; toluene diamine. DWI (2011a) reports results of a leaching study of flexible fabric-reinforced polyurethane piping. Only low levels of leaching were observed from the original liners that had been in use for many years. Chemicals were still detected in stagnation samples several weeks after new liners were installed. This suggests that it would be not be practical or effective for the manufacturer to rinse the risers as part of the manufacturing process. Concentrations of leached chemicals in samples taken after flushing tended to be low. The major unknowns were identified as a series of oligomers (compound intermediate between a monomer and a polymer, normally having up to about ten monomer units) having molecular weights of 288, 360, 432, 504 and 576. These compounds are likely to be oligomeric cyclic ethers. The chemicals were still detected in stagnation samples several weeks after the liners were installed.

##### Epoxy coatings and liners

1,1-dichloroethene; 1-methoxy-2-propanol; 4,4’-methylenedianiline; benzaldehyde; benzidine; benzyl alcohol; bisphenol A; bisphenol A diglycidyl ether; bisphenol F; butoxyethanol; diethylenetriamine; diphenyl ether; epichlorohydrin; ethylbenzene; ethylhexanol; isobutyl acetate; isopropoxy propanol; methylisobutyl ketone; *n*-butanol; *n*-butyl acetate; nonylphenol; phenol; toluene; tripropylene glycol; styrene. DWI (2007) reported 2,4-di-tert-butylphenol leaching from one brand of epoxy (now withdrawn from sale), the maximum concentration was 0.0022 mg/L.

##### Joining and sealing materials (adhesives, caulk, flux)

diethyl phthalate; ethanolamine; lead; methacrylic acid; organotins.

##### Nitrile-butadiene rubber gaskets and O-rings

1-phenylethanone; 2-(2-butoxyethoxy)ethanol; 2,4,5-trichlorophenol; 2-ethyl hexanol 2-phenyl-2-propanol; acrylonitrile; benzothiazole; benzothiazolethione; benzothiazolytiomorpholine; bis-(ethylbenzyl) ester; butadiene; butoxyethoxy ethanol; carbon disulphide; cyclooctadiene; dicyclohexyl urea; dimethyl carbamic chloride; dimethyl cyclohexyl urea; dimethyl dithiocarbamate propionitrile; dimethylethyl phenol; diphenyl guanidine; isocyanatocyclohexane; isothiocyanatoethane; mercapto-benzothiazole; methoxybenzene; tetramethylthiourea; tetramethylurea; tri(butoxyethyl) phosphate; tripropenyl triazinetrione.

##### Styrene butadiene rubber gaskets and O-rings

1,2-dichloropropane; 2,4,5-trichlorophenol; acetophenone; alpha-methylstyrene; benzothiazole; dimethyl benzene methanol; diphenyl guanidine; di-*t*-butylhydroxy-methyl cyclohexadienone; methylene chloride; methyl octanoate; phenylbenzenediamine; 1-phenylethanol; phenylethylphenol isomers; styrene; tetrabutyl urea; trimethyl quinoline.

##### Lubricants (grease, silicones, primers, sealants)

3-chloro-1,2-propanediol; cyclohexanone; *p*(*t*-butyl)phenyl glycidyl ether; silicones.

##### Solder

copper; antimony.

##### Thread compound

benzaldehyde; diacetone alcohol; ethoxylated bisphenol A dimethacrylate; lead; methacrylic acid; methanol; phenolics; tetrachoroethane; tetramethylene glycol dimethacrylate.

Polyvinyl chloride (PVC) mains manufactured prior to 1977 contained elevated levels of vinyl chloride monomer, which were prone to leaching. Water quality samples collected from a rural water system in Kansas, which had installed over 100 miles of pre-1977 PVC, contained as much as 0.014 mg/L of vinyl chloride (MAV = 0.0003 mg/L). Sadiki (1998) found organotin compounds in a water supply increased to health-significant levels as it passed through a PVC distribution system in Canada. Lead and zinc have been found to leach as well.

In a study reported in USEPA (2002), the installation of 7200 feet of cement-mortar lined ductile iron pipe caused aluminium levels in a water supply to increase from 0.005 mg/L to 0.69 mg/L over the course of two months. More than two years later, aluminium continued to leach from the lining and produced water with over 0.10 mg/L of aluminium. This was attributed to several illnesses and a 32 percent mortality rate at a receiving dialysis centre.

Alkyl benzenes and PAHs have been found frequently in drinking-water where bituminous, asphaltic and coal tar linings have been used in pipes and tanks (USEPA 2002).

Solvents used in epoxy resins, mainly xylenes and isobutyl ketone (MIBK), have been found in drinking-water a month after application; longer curing periods produced more stable linings.

The UK DoE (1990) reported a degradation product, 2,6-di-tert-butyl-p-benzoquinone, to be a common contaminant in water distributed by MDPE pipe. They also found phthalimide which proved to be an impurity related to the blue pigment copper phthalocyanine. DoE also reported that a range of phthalates and styrene were amongst a wide range of organic chemicals that leach from GRP pipe.

The chemicals detected in drinking-water can vary depending on the composition of the water, particularly pH. The presence and concentration of free chlorine and chloramine in the drinking-water can modify the chemicals being leached. Higher temperatures usually increase the leaching rate. Materials made by different manufacturers can result in different levels of taste and odour. Some materials such as cross-linked polyethylene are manufactured by distinctly different processes, eg, PEX (a), PEX (b) and PEX (c), and these leach differently, largely based on the different chemicals used as reaction initiators, reaction conditions, and antioxidants.

Durand (2005) studied the impact of pipe materials on the odour, disinfectant residual and TOC levels in drinking-water. She found domestic plumbing materials to have the potential to affect water quality characteristics such as TOC concentrations, residual disinfectant and odour when newly installed in homes, especially during the first weeks of service. Aqueous TOC concentrations increased as much as 1 mg/L for some materials. The increased TOC observed for many plumbing materials was consistent with the presence of a distinct odour or a high flavour profile analysis (FPA) intensity rating. The descriptors most consistently used to describe odours from both plastic and metallic pipes were: plastic, oily, chemical and solvent. Galvanised iron produced the worst odours that were consistently described as motor oil, with FPA intensity ranging from 4–6. This material generated the most intense odours, which were still very noticeable after 177 days. Polyethylene generated more intense plumbing associated odours than PEX or cPVC plastic material. The least odorous materials were chlorinated polyvinyl chloride and copper. Both copper pipe and epoxy-lined copper consumed residual chlorine and chloramines. Understanding the interaction of materials and water quality is a complex task.

c) Intrusion

Edwards (2004) referred to various studies that showed contaminants can be drawn into distribution systems through holes in pipes during pressure transients caused by surge or water hammer. Likewise, contaminants can enter below ground level aqueducts and service reservoirs by gravity. The volume of soil water that can enter the pipework has been estimated to range from a few mL to hundreds of gallons. Therefore leakage control and watermain repair programmes also have a water quality protection component.

LeChevalier describes a cause of transient pressure (from USEPA 2002):

Consider a pipeline on which an open valve is located at a distance downstream from a reservoir. If the valve is closed instantaneously, water will decelerate to zero velocity and the kinetic energy will be converted into pressure. The transient wave will travel upstream and downstream from the valve and ultimately reach the ends of the pipe. If the pressure wave in the pipe is not relieved (as in a surge tank), it will travel in the reverse direction back to the valve. Because the valve is closed and there is no relief for this flow, a negative pressure wave (suction) will be created at the valve. This wave will travel back and forth until the kinetic energy is dissipated by friction. The process will occur both upstream and downstream from the valve. However, the initial pressure will be positive on the upstream side and negative on the downstream side.

Pressure transients can be caused by main breaks, sudden changes in demand, uncontrolled pump starting or stopping, opening and closing of fire hydrants, power failures, air valve slam, flushing operations, fire flow, feed tank draining and other conditions including venturi effects. Intrusion can occur though leakage points, submerged air valves, faulty seals, or other openings. The report shows many instances of negative pressure.

Having an understanding of what leaks out of a reticulation network gives an indication of the risk of contaminants that could potentially enter it during a low pressure or maintenance situation. The Infrastructure Leakage Index (ILI) for the majority of New Zealand municipal suppliers is in the moderate (2.0–4.0) to high
(4.0–6.0) criteria by international comparison. Ofwat recently fined Thames Water £120 million for not meeting their water leakage rate reduction target; they had a leakage rate of 14.4 percent. By comparison New Zealand suppliers are typically >20 percent with some recording 38 percent. The World Bank suggests:



Mains breakage rates could be seen as an indicator for network condition. Many developed countries measure this and have established what they consider to be a reasonable target. It is probable that very few New Zealand water suppliers record this information at present.

d) Pressure drop

There is evidence emerging from the United States that changes in water pressure alone is sufficient to induce ingress of extraneous material into a water main. Such changes might be short term providing a pulse of contamination that will not be detected by monitoring. Work has been done by Mark LeChevalier for the American Water Works Association Research Foundation using high speed pressure recorders to show that a number of transient negative pressure events can occur. Soil lining the outside of a water main has been shown to contain total coliforms, faecal coliforms and enteric viruses. Pressure drop is of such concern in some states (eg, Ohio) that if pressure sensors indicate that water pressure has fallen below 20 psi, a boil order is issued (from DWI 2002a).

The reduction of pressure in a pipe or zone can occur in a number of ways, ie:

* high localised demand (including firefighting)
* zones with challenging geographical conditions
* pumps starting and stopping
* valves turned off in parts of a zone for maintenance
* low reservoir levels
* flow rates exceeding design capacity
* power failure for pressurised pumped zones.

Ideally water suppliers will have a distribution system management plan to address the above issues, also covering mains installation and repair (section 16.3.4). With respect to pressure, it is recommended that:

* where hydraulic modelling indicates possible risk of pipe pressure going below 10 m static head, continuous online pressure monitoring and alarms are installed at that location
* each zone has, as a minimum, one continuous online pressure monitoring and alarm installed at a convenient place near the highest risk location (furthest from the reservoir or water source).

## Operations and maintenance

Because the distribution system is the final stage before the drinking-water is consumed, there are no further barriers between the entry of a contaminant and the consumer, so particular care is required.

Proper training and supervision of the maintenance workers responsible for the distribution system is essential. This includes sanitary training and clearance (refer section 16.3.4).

Full and detailed documentation of the distribution system and its components will be undertaken in a fully comprehensive manner by most operating authorities when asset management systems are put into operation, International Infrastructure Asset Management Manual published by ALGENZ. These can be used as a tool in identifying maintenance requirements and potential trouble spots.

Some general information is also available in the Ministry of Health’s PHRMP Guide: Distribution System – Operation. The AWWA (USA) has produced standards for the disinfection of water treatment plants, water mains, and water storage facilities, and a standard for distribution systems operation and management, see ANSI/AWWA references.

### Service reservoir operation

Water quality can be influenced by periods of storage. To minimise the effects, good operating practices and regular maintenance are required.

Mixing and turnover

Reservoir operation should encourage turnover of water at least every few days. If a reservoir is filled and remains so, it is likely that fresh water is going directly to the users while the water in the reservoir sits for considerable time. This situation is common where the inlet and outlet mains are the same pipe, often supplied by a pump.

The reservoir should draw down to ensure mixing and renewal is occurring. The flow-balancing feature of a reservoir (allowing constant treatment plant operation, attenuation of peak flows, etc) requires the volume to change. The minimum operating level to allow for emergency storage should be assessed and the reservoir operated accordingly.

Quality may deteriorate rapidly if the water in a reservoir is not kept fresh. The chlorine will either combine with any residual organic material in the water to form mono-, di- and tri-chloramines, or dissipate into the atmosphere. The former may result in poor taste and odour (complaints will be received at about 0.05 mg/L of trichloramine). Dissipation will result in inadequate chlorine residual to prevent regrowth of micro-organisms.

Some service reservoirs or tanks are designed to provide flow to high areas during peak summer demand. Consequently, the water may sit there for many months. Procedures for dealing with this should be documented in the WSP.

Reservoir inspection

Reservoir inspection can be classified into the following categories:

* inspection of hydraulic controls
* inspection of cleanliness and security
* inspection of structural condition. The underside of the roof of buried reservoirs needs to be inspected for drips entering the reservoir through cracks in the roof material or breaks in the jointing material. The sound resulting from leaks tend to come from a consistent area, whereas the sound from condensation drips tends to be more random. Leaks often occur where roots can be seen to have penetrated the roof.

Hydraulic controls should be part of a routine maintenance programme. Typical frequency of inspection that valves are functioning correctly would be quarterly.

Cleanliness and security should also be checked routinely, typically at least quarterly depending upon both the access security risk and the testing programmes in place. The water surface should be examined for floating objects. Thistledown is an indicator that wind-blown objects are able to get into the water, and feathers or nesting material is evidence that birds have found a wee gap. Oil slicks and road dust have been found on the water surface of service reservoirs near busy roads. The clarity of the water should be adequate to examine the bottom of the reservoir with the aid of a reasonable torch or similar. In many situations, a clean piece of PVC pipe will be useful to stir the bottom to give an indication of sediment build-up. Divers may be used, provided cleanliness procedures are followed. They will provide a better picture of how much sediment is present, and in performing structural checks (floor displacement, joint sealant positions, deterioration etc) than is possible from above the water surface. They may also be used without disruption to the supply.

A person experienced in detecting cracking, corrosion, and foundation stability should check structural integrity regularly. This may be the system operator or an engineer (who may further train the operator).

Reservoir maintenance cleaning

Water reservoirs can act as sedimentation tanks. Over time it is usual for sediment to accumulate on the floor of the reservoir. It is also possible that slimes, algae (if light can penetrate), or chemical deposits will accumulate on the interior walls. Eventually the accumulated material can adversely affect the quality of the water.

The initiation of a reservoir cleaning procedure may be due to any one of:

* customer complaints about taste, odour or appearance
* water quality testing showing quality degradation
* random checking showing a clean is due
* the sludge depth is reaching the height of the outlet
* planned maintenance procedures or design modifications.

If the procedure has been initiated by customer complaints or finding *E. coli*, the problem is urgent and should be attended to directly.

Planned maintenance frequency requires the accumulation of experience of the particular reservoir; there is no golden rule for how often any particular reservoir should be cleaned. The frequency is likely to be around six months to four years, rather than some shorter time interval. A regular inspection programme, coupled with water quality testing, is the best way to assess this frequency. A key variable is the quality of the incoming water; if it is of low quality, more sediment will be trapped and more organic growths may be expected.

Reservoir cleaning will involve time and cost and may cause disruption of supply to customers. These factors make a lower frequency preferable to frequent cleaning. In assessing the frequency, the bottom line is minimising risk to public health. The free available chlorine content of the water after refilling should be at least 0.30 mg/L and ideally this residual should exceed 0.20 mg/L 24 hours later; any lower residual suggests that the reservoir was refilled while still dirty. Samples from different depths should be collected for *E. coli* testing. Supplementary chlorination will be required if the chlorine dissipates more rapidly than expected, or if *E. coli* are found. The procedure for reservoir cleaning and restoration to service should be documented in the WSP.

### Reticulation operation

The main causes of recontamination of water in the distribution system are poor mains laying, the use of inappropriate types of distribution pipe/fittings, poorly planned and coordinated maintenance systems, and inadequate training/supervision of staff or contractors. These can be overcome by good system design, a good asset management system, writing and following a suitable WSP, and appropriate training systems.

Distribution systems are generally designed to ensure hydraulic reliability, which includes adequate water quantity and pressure for fire flow, as well as domestic and industrial demand. In order to meet these goals, large amounts of storage are usually incorporated into system design, resulting in long residence times, which in turn may contribute to water quality deterioration. Section 16.2.6 discusses water quality issues that can result from leaks and poor pressure control.

Should a main break require some significant time to repair, a temporary bridge between fire hydrants may provide some continuity of supply. This, coupled with tanker delivery, may provide a sufficient quantity of drinking-water. Public notices (eg, radio or leaflet drop) advising whether boiling the water is needed and advice on water conservation will be required. The procedures to be adopted following main breaks should be covered (or referenced) in the WSP.

Some pump stations are designed to provide pressure to high areas during peak summer demand. Consequently, the water may sit in the associated pipework for many months. Procedures for dealing with this should be documented in the WSP.

The most direct sources of contamination of reticulated water supplies arise from:

* older style ball hydrants that will open of their own accord under loss of system pressure
* open fire hydrants during mains repairs or hydrant or pressure checking
* direct entry into broken mains or services
* backflows from individual properties.

Most authorities have replaced the old ball hydrants. The few that remain may be at points that are difficult to shut down to allow their replacement.

Figure 16.3 shows how dirty the water can be during flushing. When testing hydrants, or when flushing a main, it is important to continue the flushing procedure until the water appears to be clean. For example, grit has been known to block consumers’ water meters and Ajax valves. WRF (2015b) provides an in depth discussion on the removal of manganese from water mains. Hydrant testing guidelines are outlined in NZ Fire Services Firefighting Water Supplies Code of Practice, SNZ PAS 4509:2008.

Fire hydrant contaminant entry after draining down for repair can be minimised by the use of standpipes on the hydrants. This restricts the level of the water drained from the main and is thus unpopular with service personnel. This is primarily a training and attitude matter – most service trucks carry a standpipe. Direct contamination entry during repair is also essentially a training and attitude issue.

During small-scale repairs, individual properties may be supplied from a neighbour’s garden tap, often to the garden tap of the property without a supply. In such cases, the loss of integrity and use of non-disinfected piping may compromise the safety of the water. Suitable warnings should be issued about potability. Suppliers should have documented procedures for informing customers of interruption to supply and ensure that all staff complies with these. There is a natural tendency to stop the flow (completely!) and pump out a hole to see what is going on. To do otherwise requires training.

Figure 16.3: Fire hydrant standpipe being used to flush a water main



Backflow prevention

Backflows are defined as the flow of (possibly contaminated) water from the consumer’s premises into the public supply.

Backflow and backsiphoning events are more common than most water suppliers and consumers realise or acknowledge. Overseas studies have indicated about 12,000 incidents per annum in a population of 1,200,000, a frequency of about 1 incident per year per hundred people served. Studies have not been reported in New Zealand but are probably similar. Not all of these events result in illness, but all represent a potential incident.

From 1981 to 1998, the CDC documented 57 waterborne outbreaks related to cross-connections, resulting in 9734 detected and reported illnesses. The USEPA compiled a total of 459 incidents resulting in 12,093 illnesses from backflow events from 1970 to 2001. The situation may be of even greater concern because incidents involving domestic plumbing are even less recognised (WSTB 2005).

The Australian Plumbing Code Development Research Report (2015) summarised cases of backflow incidents and cross-connections which occurred predominantly in the USA, with some in Australia, between the years 1933 and 1990:

* the most common premises type was colleges and schools (18 percent), followed by ‘not recorded’ (10 percent), and shipyards (8 percent). Apartment buildings, houses, farms, and ‘chemical plants’ each accounted for 3 percent of the cases
* main breaks and pressure drops (fire service drawdown, etc) were involved in 29 percent of cases. The most common specific cause was human error (39 percent), followed by equipment failure (31 percent); accidents/natural disasters (12 percent), then sub-standard work (6 percent)
* backsiphonage (43 percent) was more common than backpressure (18 percent); accidental cross-connection accounted for 25 percent of cases
* the most common pollutants were sewage (14 percent), fire-fighting water (10 percent), and corrosion-inhibitors (8 percent).

The American Backflow Prevention Association estimated the extent of backflow incidents in the USA to be around 100,000 per day where some type of contaminant infected a municipal water supply, including those where no harm was caused. The most common cross connections reported were from irrigation, followed by fire systems, garden/washdown hoses, and boilers.

It is necessary for the water supplier to ensure that there is sufficient positive pressure through the pipes to prevent any backflow or inflow that could contaminate the supply. The network must be monitored to ensure that this is so. This is particularly important when pipes are buried in areas where the water table is high. DWI (2008 and 2011) discuss the effects of abnormal pressures on water quality in some detail. Their main recommendations were:

1 Additional proactive measures are not required to minimise an already low probability of very low pressures occurring.

2 The practice of designing distribution systems with alternative routes to most customers (ie, with loops) should continue.

3 Good practice should be followed with respect to:

* opening and closing valves and hydrants slowly
* running hydrants at the lowest necessary flow
* returning mains to service (disinfection)
* disinfecting local mains which have drained as a consequence of work on other mains
* implementing soft start and stop for pumps
* maintaining PRVs and maintaining pressures during maintenance.

The network should also be modelled in some way to ensure that the necessary capacities and water pressure criteria are met under all conditions. This may be done by hand, or, more commonly, by computer modelling. The most powerful method for modelling distribution networks is by the use of purpose specific software packages.

For their part, the customer must also prevent backflow into the system by the installation of specific devices to prevent it. Backflow prevention requirements were set out in the Water Supply Protection Regulations 1961, which have been superseded by the HDWAA; backflow is covered in 69ZZZ.

The Building Act (2004) *Approved Document for New Zealand Building Code Water Supplies* Clause G12 (2nd edition) section 3.41 states that backflow protection shall be provided wherever it is possible for water or contaminants to backflow into potable water supply systems. There have been many accounts of faulty installation (eg, installed back-to-front) and inadequate servicing (eg, the annual inspections are often overlooked). Figure 16.4 shows a backflow prevention device being commissioned. The objective is to safeguard the health of people within the building by installing a backflow device at each source of possible contamination. Approved methods are set out in this Act and include:

* air gaps reduced
* pressure zone devices
* double check valves
* vacuum breakers.

Further information is available in the *Cross-Connection Control Manual* (USEPA 2003). The manual includes discussion on a series of well-illustrated case histories.

An appropriate device is required for the hazard level. G12 has definitions of the hazard levels, High, Medium and Low, and lists of possible examples for each. As well as protecting the internal water supply system, G12 section 3.1 requires that water drawn from the water main shall be prevented from returning by avoiding cross-connections or backflow.

Figure 16.4: Commissioning a backflow prevention device



Backflow prevention programmes are in place for new service connections but a high percentage of properties in New Zealand have supply connections predating the Building Act 1991.

The Backflow Special Interest Group of NZWWA, in consultation with the Building Industry Authority (BIA), produced Backflow Prevention for Water Suppliers, Code of Practice (updated 2006, revised 2013), in response to the Ministry of Health Public Health Risk Management Plan (PHRMP) Guide – Distribution System – Backflow Prevention.

Once a water supplier has undertaken the risk assessment as part of the WSP process, then the code of practice (CoP) provides a best practice approach to reducing the risk of backflow.

The primary focus of the CoP is on containment (boundary protection) and the protection of the public water supply. As a result, there is a need for the development of policies and the risk assessments in order to support this focus. The CoP can be incorporated into water suppliers’ water bylaws.

The biggest question of concern for most water suppliers when developing a policy is that of the ownership of containment devices. Ownership in the CoP is primarily with the water supplier outside the boundary or upstream of the defined point of supply. Devices and testing is at customers’ cost through connection charges and supply agreements.

There are benefits to the water supplier owning the containment devices in terms of better asset management and not coming into conflict with the Building Act (2004). If the water supplier chooses not to own the containment devices then a building consent is required. In both cases the water suppliers and customers’ responsibilities are detailed including payments of costs, enforcement, change of use, record keeping, etc.

Testable containment devices are recommended for all non-domestic connections. A New Zealand testing standard has been produced (Master Plumbers 2018). The device selection and specification is the responsibility of the water supplier regardless of ownership, and guidelines are provided in the CoP. All domestic connections should include at least a dual check device, under the hazard level of very low introduced in the WSP. Fire supplies are covered in detail. In consultation with fire industry specialists it was deemed best practice for fire sprinkler systems that the containment device is located in the valve house as per the G12.

The CoP states that the person undertaking the annual testing of containment devices shall have passed a 40 hour backflow testers’ course. Surveying of existing sites is covered in the CoP. Persons who survey existing buildings to assess the overall hazard level and if the current backflow prevention is adequate, must also have the appropriate qualifications.

Metrowater found discrepancies in backflow test results during an audit of Auckland City’s public water supply. This prompted a request that all backflow test kits used by IQPs (Independent Qualified Persons) within the Auckland Metrowater zoned area be recalibrated and certified (as per the NZWWA Backflow Prevention for Drinking Water Suppliers Code of Practice 2003). One Telarc Registered Laboratory found that 97 percent of the kits they tested failed. Test kits that fail require repair and recalibration before they can be certified. Certification of backflow testing equipment is of vital importance to the accuracy of the tests being carried out and ultimately the protection of the water supply. It is therefore recommended that test kits be recertified every 12 months by a Telarc registered laboratory.

NZWWA in conjunction with the Master Plumbers, Gasfitters and Drainlayers NZ Inc have formed a committee to assist Standards New Zealand produce a new standard ‘Field testing of backflow prevention devices and verification of air gaps’; a draft appeared in 2010. This new standard is being developed as a replacement for AS 2845 Water supply – backflow prevention devices, Part 2 Registered air gaps and registered break tanks, and Part 3 Field testing and maintenance of testable devices. It will be more suitable for use in New Zealand as it will reflect the regulatory environment and the procedures currently in use.

Backflow and backsiphoning are discussed in WHO (2006, Chapter 15).

WRF (November 2016): Automatic Meter Reading (AMR), and Advanced Metering Infrastructure (AMI) systems have shown that numerous meter communicating systems exist to detect reverse flows and transmit data from residential meters to utilities. Data collected from over 60 districts in the American Water system from September 2012 to August 2013 were used to create a large database (over 1,000,000 individual meter reads). This showed over 14,500 separate reports of reverse flows, with monthly occurrence ranging from a low of 535 reports in September 2012 to a high of 1,761 in March 2013. With the advent of a new meter data management system at American Water, instituted during 2015, a more comprehensive analysis that distinguished between major (10 gallons or more) and minor backflows was conducted to cover all activity during 2015. This showed that the vast majority of backflows are minor in nature. The data from major backflows were organised in spreadsheet form from the meter data management system and covered several months. Data were then used to detect the categories of backflows and prioritise subsequent investigations. These spreadsheets were later augmented by graphic displays of data that aided in rapid identification of possible operational issues from multiple backflows in neighbourhoods (meter routes) and individual locations with repeated backflow events over time.

Mains cleaning

Water mains gradually accumulate sediments and corrosion products, particularly where flow velocity is low. In some cases biofilms will form that must be cleaned off (biofilms are discussed in section 16.4.1). There are two main methods for cleaning mains: flushing and pigging.

Flushing, by running the main at a high velocity (ideally 1.5–2 m/s) to waste, will generally control the rate of accumulation. Flushing must continue until satisfactory clarity is obtained. This is a routine task that may need to occur every few months, or only once every two or three years. Problem dead-end mains may require weekly flushing. Some water suppliers only flush their pipes on an as needed basis. The procedure and programme should be documented in the WSP or other appropriate manual. Inclusion of air can improve the flushing performance.

The flushing water is typically disposed of to the stormwater drain. Water with significant chlorine levels has the potential to kill fish, and/or the organisms on which they feed. It may be necessary to neutralise the chlorine. When this is done with chemicals such as sodium thiosulphate, they should not be overdosed, as they will also damage the receiving environment.

Pigging involves passing a fluid-propelled object through an isolated section of the pipe. A foam plug is often used as the pig. It is normally the same diameter or slightly larger than the water main and is shaped like a torpedo. Care should be taken to isolate the service connections so that poor quality water and pieces of pig are contained.

When foam pigs are used then the type of pig, the distance travelled, time used, and its efficiency should be recorded in order to appraise the cleaning operation. If a scraper is to be used then notice should be taken of the type and quality of the lining inside the pipes, so the integrity of the lining and joints is not compromised. This may lead to the reapplication of interior linings.

Asbestos cement mains and mains less than 150 mm diameter are not normally pigged.

CCTV pipe inspection may be needed before and after cleaning.

WRF (2016a) reports the findings of an extensive study into the accumulation and release of metals in the distribution system, and evaluates mains cleaning methods.

Reticulation system records

**Record plans:** Most community water supply plans start out with initial construction plans showing where and how the original mains were laid. These plans are still used as part of contract drawings for most construction work.

There is generally a requirement for as-built plans to be completed showing departures (if any) from the original design and position.

These construction plans, whilst giving key details of many items, are not suitable for the primary records purpose of what is buried where, and how the whole system is linked.

To provide this function, most communities have indexed records plans of underground services, including water mains, on a street basis, normally organised into sheets. The sheet will often list construction drawing numbers for detailed information if needed.

Many water suppliers use geographic information systems (GIS) to record the location and other attributes of their underground pipe networks. Further software is used for assessment management systems (AMS) with the most common in current use called MIT-Hansen ‘PAMS’ (pipe AMS). These systems allow maintenance records and other relevant data to be stored as well as total asset evaluation for accounting purposes. Asset Management is described in detail in the *International Infrastructure Asset Management Manual* published by ALGENZ.

**Fire flow records:** Most communities that have fire hydrants to provide fire protection also have a fire brigade. A routine brigade task is to flow test the hydrants in their area, partly for the flow information, but also to check markers are present, etc. In some areas, this data is logged by the council on the PAMS; in others it may be available as a paper copy of the fire brigade hydrant sheets. It is very useful data on the reticulation system performance and will highlight problem areas.

Mains relining

As water mains become old and reach the end of their useful lives, their performance diminishes gradually, resulting in high maintenance costs, deterioration of water quality, loss of hydraulic capacity, and a significant increase in customer complaints. Cleaning and lining of a poorly performing water main will decrease customer complaints and will improve water quality, flow, and pressure significantly. This will improve the long-term performance of the pipe and improve the reliability of the system. Rehabilitation of water mains using cleaning and lining results in significant cost savings compared to replacement. In North America, most of the water main rehabilitation is conducted using cement-mortar lining. Alternatives to cement-mortar lining of water mains are epoxy lining and polyurethane lining.

The Water Research Foundation (WRF 2015) with WERF and USEPA produced guidelines for water main inspection, repairs and maintenance. Chapter 6 is titled “Pipe lining system selection and design”.

In the United Kingdom, epoxy has been used as the preferred lining material in rehabilitation of water pipelines. In the last few years, however, polyurethane has become the most widely used lining material in the UK. WRF (2010) reports results of a series of tests.

The impact of cement-mortar material on alkalinity in general terms was the same for all four test waters increasing it to 600 mg/L as CaCO3 and then stabilising at 100 mg/L after day 19 of the test. The background alkalinity of the test waters was 35 mg/L.

The pH after the first day in contact with the cement mortar was 12.4. After 30 days in contact with the cement mortar and nine changes of water, the pH was 11.5.

Increased levels of calcium were measured over a 14-day period, after which calcium stabilised and remained at 7 to 9 mg/L as calcium, slightly below the background concentration of 11.5 mg/L.

Aluminium increased from day 1 to 9, then decreased significantly at day 11, probably due to a lower contact time of two days. The concentrations of aluminium exceeded the drinking water secondary maximum contaminant level of 0.2 mg/L for the first nine days of the test.

Chromium concentrations increased to 0.07 mg/L in 24 hours, but decreased significantly on day 9. Cement-mortar lining increased consumption of chlorine. The total solids concentrations increased up to 1500 mg/L on the first day and declined substantially after day 9.

In the presence of polyurethane, the pH was reduced from 8 to about 6. The pH drop was observed within 24 hours and persisted for 30 days. Polyurethane consumed chlorine. The consumption rate decreased over time, but still persisted at the end of 30 days of testing.

Organic carbon (TOC) was leached from polyurethane, with a greater amount leached in the presence of chlorine than in its absence. Leached total organic carbon reacted with free chlorine to form up to 30 μg/L of five regulated haloacetic acids (HAA5), but no trihalomethanes were detected; traces of chlorophenyl isocyanate were detected. The low pH of 6 would favour HAA5 formation over THM formation. None of the THM or HAA5 concentrations exceeded the drinking water standard of 80 μg/L and 60 μg/L, respectively. Weak to moderate odour intensities were released from the polyurethane and it persisted for the 30 days of the study.

Epoxy exposed to each of the three water types produced significant concentrations of TOC (3.5 to 6.3 mg/L) during the first 24 hours of exposure to water. By the second 24‑hour exposure period the TOC decreased substantially. By the end of the 30 days, each of the water types exposed to epoxy had TOC present in concentrations between 0.5 and 1.7 mg/L, with chlorinated water having the highest TOC concentration.

Epoxy reduced the concentrations of chlorine. Mature pipe samples lined with epoxy also reduced the disinfectant residual concentrations.

Water exposed to epoxy showed some increase in the THM and HAA5 concentrations, but none of these increases exceeded the drinking water standards. The increases in THM and HAA5 concentrations were greatest in the chlorinated water. Bisphenol A was detected in substantial concentrations (22 to 33 μg/L) in all three water types exposed to epoxy. Concentrations were greatest during the initial 24 hours and were highest in both chlorinated and chloraminated waters. Bisphenol A decreased significantly by day 4, but trace concentrations were still detected on both day 9 and 14. No other SVOCs were detected in the samples.

### Maintenance of disinfection residual

Most water supplies in New Zealand maintain a residual of free available chlorine throughout their distribution system. This is generally acknowledged to offer a good initial kill of most bacteria and viruses, and a long-lasting residual able to continue disinfecting within the distribution system, which helps limit regrowth, and to assist in countering any low level microbiological contamination. However, most contamination events in the distribution system will probably be too large for low levels of FAC to deal with; most ingress is likely to be as a result of a mains break or serious backflow. Therefore a major benefit of maintaining FAC is that it acts as an indicator of system security as large/sudden changes in FAC residuals would indicate ingress or contamination of some kind. Regrowth of organisms in the distribution system is discussed in WHO (2003, 2004).

The DWSNZ specify requirements for sampling of *E. coli* and free available chlorine levels within each distribution zone. In most cases there is only one point where chlorine is dosed, usually at the treatment plant. If the distribution zone covers an extensive area or is an area of elongated shape, a high chlorine residual may be needed near the plant in order to get the required residual at the most remote locations. Alternatively, supplementary chlorination can be installed to boost the residual at strategic points in the network.

Free available chlorine levels in the network are typically in the range 0.2 to 1.0 mg/L. Higher concentrations are resisted due to cost and taste and odour concerns. Free available chlorine (FAC) has a noticeable flavour that increases with concentration. Most taste and odour complaints relate to the formation of inorganic and organic chlorine compounds, often in relation to pipes with biofilms, deposits, or corrosion products, particularly when the water temperature increases. Also refer to Chapter 18: Aesthetic Considerations.

In addition to biofilm, the rate of loss of the chlorine residual after the dosing point also depends on:

* the retention time
* compounds that react slowly with chlorine remaining in the water following treatment
* contaminants entering the water in the distribution system
* the state of the water mains
* water temperature.

This is why some *E. coli* monitoring is still required even when the water contains FAC.

The DWSNZ (section 4.4.6 for compliance criteria 6A and 6B, and section 4.4.7.5 for compliance criteria 7A and 7B) require that remedial action be taken in the case of *E. coli* contamination of a drinking-water supply distribution zone. These actions include doing an *E. coli* count, increasing disinfection, undertaking a sanitary survey, target sampling and informing the drinking water assessor or other Ministry of Health designated officer.

### Barriers against recontamination during maintenance

Water leaving a well-designed and operated treatment plant will contain very few micro-organisms. Therefore, any significant microbiological contamination of the drinking-water received by the consumer will probably have occurred in the distribution system.

The main barrier against the recontamination of water supplies in the distribution system is a sound, well-designed maintenance regime. It is important that operational procedures cover all aspects of the maintenance of water quality from the treatment plant, through the distribution system, to the consumer’s tap. These should be addressed in the WSPs, along with possible remedial actions for when problems have been identified. See section 16.2.6 for possible issues related leakage and pressure problems.

Operational procedures (work instructions if part of a quality management system) should be produced covering (refer section 16.3.2):

* new mains disinfection, mains cleaning and repairs
* backflow prevention
* overcoming quality problems induced by the distribution system (eg, dead ends, pressure variations, build-up of corrosion products)
* updating as-built drawings
* service reservoir maintenance and operation
* consumer complaints relating to the quantity and quality of drinking-water (details and action taken)
* leak detection, see NZWWA (2002) and WHO (2001).

Maintenance programmes should include the recording of the time and type of various repairs and cleaning options used.

Staff working on water reticulation systems and their equipment offer potential sources of contamination. The following general guidelines are recommended most strongly to minimise these risks:

* operators and maintenance workers should work only on the water supply, and not alternate between water supply and sewerage
* staff and contractors need to be trained to use the appropriate hygienic practices at courses such as run by the Water ITO. Regular refresher courses are desirable
* vehicles and tools used on water supply work must be kept totally separate from those used in sewerage work
* a high standard of cleanliness must be adhered to in maintenance vehicle interiors
* ablution facilities must be available, and used
* operators and maintenance workers should report any gastrointestinal illness, have faecal specimens taken for analysis at the outbreak of such illness, and be placed on work not involving handling water supply system components until a medical certificate of clearance is obtained following such illness
* prior to employment on the water supply system, and on an annual basis thereafter, or following overseas travel to countries with a significant level of endemic waterborne disease, operators and maintenance workers should obtain a medical clearance from being carriers of potentially waterborne disease. The clearance required under this and the previous guideline is likely to be obtained from a laboratory evaluation of faecal specimens taken over three consecutive days and tested for the presence of *Shigella*, *Salmonella*, *Campylobacter*, hepatitis A virus, and *Giardia*, *Cryptosporidium* spp or antibodies
* the Water Supplies Protection Regulations (1961) required the disinfection of new mains and mains repairs to the satisfaction of the Medical Officer of Health in situations where significant contamination potential exists. Under the HDWAA, this is now to be covered in the water supplier’s WSP. Drinking-water assessors must approve WSPs
* for further guidance, refer to the MoH PHRMP Guides (see References); for example, Appendix 1 in Guide D3 discusses Good Hygiene Practices for Staff Working on Drinking Water Supplies, and Appendix 2 covers Cleaning and Disinfection of Mains.

Chapter 5 (Precautions during Construction and Repairs) in WHO (2004) states:

Engineering work on distribution systems presents risks of widespread contamination of water supplies. The risks depend on factors such as the degree of pollution at the construction or repair site, the method of construction or repair, the ability to contain potential contamination by valving and, most importantly, the cleanliness of personnel, their working practices and the materials employed. The following activities may present risks of contamination with pathogenic micro-organisms:

* construction of new pipework or the abandonment of existing pipework
* renovation work using either structural or non-structural linings, such as polyethylene slipliners or spray-on coatings
* repairs, either emergency or planned, that involve pressure loss or breaking into the inside of a pipe
* reconnecting a water main after it has been taken out of service for an extended period.

See also section 8 in WHO (2014). Section 8.1.8 discusses making connections to the mains. Section 8.1.10 itemises procedures that need to be addressed in standard operating procedures or water safety plans for repairing mains. Section 8.1.11 covers construction of new mains.

The USEPA (2002) prepared a paper on *New or Repaired Water Mains*. It refers to ANSI/AWWA Standards 600-606 which address pipe installation procedures, as well as guidelines on inspection, trench construction, pipe installation, joint assembly, flushing, pressure and leakage testing. It also refers to AWWA Standard C651 for Disinfecting Water Mains.

Emergency repairs present the greatest risks: locating valves, dealing with consumers and traffic, the presence of adjacent services and the need to restore an essential supply all create difficulties when the location and timing are unplanned. Minimising the risks arising from both emergency and planned engineering work depends on:

* having documented protocols
* adopting general precautionary working practices
* using health criteria to select personnel
* implementing effective procedures for cleaning and disinfection
* assessing the risks and monitoring the effects of both planned and emergency engineering work.

Earthquakes can cause breakages in the distribution system, leading to contamination. In the month following the February 2011 Christchurch earthquake, over 5000 samples were collected for *E. coli* testing; 155 contained *E. coli*. Mapping the results indicated the areas with the greatest need for flushing.

WHO (2004) addresses each of the above topics. Water suppliers will find those 14 pages will provide an excellent basis for preparing their water mains installation and repair manual. WHO (2011a) provides technical notes covering a range of emergency situations. Excess pressure can lead to mains breaks. The breakage rate needs to be monitored to find out if it is excessive. A survey conducted in North America reported an average of seven breaks per 100 km of water main per year; in Australia in
2011–2012, the rate was 13 breaks per 100 km of water main; reported in WHO (2014).

Earlier, three cities in the Auckland region proposed a code of practice (Utting et al 1993). This has not eventuated yet. They used two main reports in preparing their paper: AWWA (1990) and WAA (1988).

They considered that the code should cover three situations, and they then offered some suggestions:

* new mains
* repairs maintained under positive pressure
* repairs where there is pressure loss or full draining of the line.

New mains

* Chain of cleanliness established for all equipment and fittings prior to use.
* Thoroughly flush or swab mains to remove debris.
* Disinfect to achieve a minimum chlorine C.t value of 5,000 mg/L.minutes.
* Flush chlorinated water to waste, with prior neutralisation and discharge approvals if required.
* Sample for *E. coli* at at least two locations.
* Commission mains when results <1 *E. coli* per 100 mL.

Repairs maintained under positive pressure

(Generally limited to small diameter pipes and wrap-around clamps.)

* Chain of cleanliness applied to repair equipment and fittings.
* Good standard of work and equipment.

Repairs where pressure is lost or line drained

* Chain of cleanliness applied for all equipment and fittings prior to use.
* Isolate the section of main and drain (or pump) the water from the break.
* Excavate below the main to create a sump that can be dewatered.
* Apply chlorine solution to trench walls, pipe and fittings.
* If contaminated water is likely, apply chlorine to a C.t value of 500 mg/L.minutes, or notify consumers to boil water,[[1]](#footnote-1) or supply drinking-water.
* Thoroughly flush main and affected consumer connections before restoring service.
* Sample for *E. coli* randomly for low risk situations, and mandatory for all other cases.

WSTB (2006) includes: the following summary shows results of a survey of distribution system workers at three different utilities (eastern US, western US, and western Canada) on the potential for external contamination to occur during water main repair and replacement activities. Given that the average number of water main repairs a year for a single utility ranges from 66 to 901 (which corresponds to 7.9–35.6 repairs per 100 miles of pipe per year), it is clear that exposure of the distribution system to contamination during repair is an inescapable reality.

|  |  |
| --- | --- |
| **Activity** | **Responses (%) from workers, 3 different utilities(A, B, C)** |
| ***Occurs often*** | ***Occurs* s*ometimes*** |
| **A** | **B** | **C** | **A** | **B** | **C** |
| Broken service line fills trench during installation | 46 | 75 | 56 | 39 | 25 | 33 |
| Pipe gets dirty during storage before installation | 53 | 75 | 22 | 43 | 25 | 33 |
| Trench dirt gets into pipe during installation | 24 | 100 | 39 | 37 | 0 | 44 |
| Rainwater fills trench during installation | 20 | 25 | 5 | 60 | 75 | 83 |
| Street runoff gets into pipe before installation | 30 | 0 | 11 | 61 | 38 | 67 |
| Pipe is delivered dirty | 4 | 25 | 17 | 33 | 63 | 22 |
| Trash gets into pipe before installation | 24 | 0 | 0 | 56 | 50 | 11 |
| Vandalism occurs at the site | 15 | 0 | 0 | 35 | 0 | 5 |
| Animals get into pipe before installation | 0 | 0 | 0 | 11 | 0 | 11 |

Source: Reprinted, with permission, from Pierson et al 2002. © 2002 by American Water Works Association.

DWI (2015) includes the statement: *By some estimates, there are over 700 water main breaks in the United States every day that require repair*. This document states that as part of the Risk Management Strategy, four categories of breaks and responses can be developed and summarised.

* Type 1: positive pressure maintained during excavation and repair
* Type 2: positive pressure maintained during excavation, followed by controlled shut down for repair
* Type 3: loss of pressure at break site/possible local depressurisation
* Type 4: catastrophic failure, loss of pressure at break site, and widespread depressurisation.

They then present their Table ES which tabulates responses for different main break types. This excellent summary was developed by the UK Drinking Water Inspectorate in conjunction with the Water Research Foundation (previously AWWA Research Foundation in the US).

A study of 69 incidents in five water supplies in Sweden found that a significantly elevated risk of gastrointestinal illness, especially vomiting and AGI, was linked to incidents in the drinking water distribution with children in the 2–5 year age group at the highest risk. The results give support to the hypothesis that pathogens causing gastrointestinal illness originate from an external source, such as sewage, as an elevated risk of vomiting and AGI was associated with drinking water pipelines being on the same level as sewage pipes in trenches. In contrast to other studies, this study showed that there was still an elevated risk of gastrointestinal illness after flushing was used as a safety measure. Additional safety measures should therefore be considered as current safety measures and routines may not be sufficient for reducing the risk of gastrointestinal illness (Säve-Söderbergh et al 2017).

## Aesthetic considerations

There are many constituents that affect the taste, odour, colour, clarity or general appearance of the water. Some of these are listed in Table 2.5 of DWSNZ. Chapter 18 of the Guidelines discusses this topic in more detail. Datasheets have been prepared for a large number.

In some circumstances, the aesthetic quality of the water can deteriorate in the distribution system. See section 16.2.6 for a discussion on chemicals that can impart tastes and odours by permeation through or leaching from the pipework.

The impact and detection of aesthetic problems are detectable by consumers, whereas the more serious chemical and microbiological contaminants are not. Aesthetic considerations are covered in more detail in Chapter 18.

### Wholesomeness

Note that the HDWAA states in 69W “Every water supplier must take reasonable steps to ensure that the drinking water supplied by that drinking water supplier is wholesome”. And in 69G, “wholesome, in relation to drinking water, means:

a) being potable, and

b) not containing or exhibiting any determinand in an amount that exceeds the value stated in the guideline values for aesthetic determinands in the DWSNZ ...”.

Aesthetically poor water quality in the distribution system can be caused by a number of factors. In some cases the quality of the water can deteriorate to the point where it affects compliance with the DWSNZ.

Construction causes

The installation of pipes should maintain cleanliness, particularly from plugs of mud or similar which will be detected by customers as cloudy water. Some construction materials can also impart taste and odour to water, such as solvent odours from some reservoir linings, and these may react with chlorine to impart tastes and odours. Plastic pipes should not be laid in land contaminated by chemicals.

Hydraulic causes

Water that is retained in the distribution system may go stale. The reasons for water standing in sections of water pipelines include: small areas fed from a large service reservoir or tank, large-sized dead end mains for fire flows with very low flows, large-sized mains installed for future growth but supplying only a few properties, and dead spots in ring mains (a balance point of zero flow under most flow conditions). The most common solution to stale water is to flush the main regularly, weekly is normally adequate.

Stale water can affect water quality in the following ways:

* Residual chlorine will dissipate with time, leading to the loss of consumer protection.
* Chlorine may form chloramines with any organics or ammonia present. There is a link between water with elevated colour levels and trichloramine formation at low pH. Complaints relating to trichloramine (albeit rare) will usually be of excessive chlorine smells because the trichloramine breaks down on release to air, giving off free chlorine. The remedies to these problems are to remove more of the organics in the treatment process and/or flush water to waste at frequent intervals, less than weekly.
* Harmful disinfection by-products such as THMs and HAAs can form with prolonged exposure of treated water to free chlorine. This issue is discussed separately in Chapters 10 and 15.
* Alkalinity and pH levels may increase due to the dissolving of cement based pipe lining. This is a particular problem with aggressive water and asbestos cement and concrete lined steel or ductile iron pipes. This problem eases with time (a few years) but initially can be very severe: pH levels may exceed pH 10. This can lead to reports of ‘green coffee’, a drying or burning sensation in the mouth, and an absence of lather when shaving, etc.

Sediments, in some cases including precipitates of alum floc, iron, and manganese, or fine sand from hydrated lime or groundwater, can collect in the system, only to be dislodged by reverse flows or higher flows (for example fire flows). Regular flushing will help to control this.

Chemical causes

Water quality may be affected by interactions with the reticulation pipework. These interactions may be divided into those with soft (aggressive) water and those with hard water. The chemistry of water is described in Chapter 10. Plastic pipes and fittings should be those approved for water supply use, see section 16.2.6.

Soft, aggressive water

The most direct result of poor water chemistry is corrosion of the pipe materials, particularly the metal components. Consumers easily notice oxidised iron (eg, from the pipe in Figure 16.5) and copper products, but lead also corrodes out of some fittings. In severe cases the concentration of the corrosion products can exceed the MAVs in the DWSNZ. This is discussed further in Chapter 10. Many corrosion issues in water supply are discussed in AWWA (1990) and AWWA (1996). Corrosion products also reduce the water flow through the distribution system.

Figure 16.5: Example of corroded water pipe



The problems will be worsened by unstable or inappropriate water pH. A stable pH is essential for developing and maintaining effective passivating layers on metallic pipe surfaces. The pH of water leaving treatment will normally be controlled. The pH of the water can change in the distribution system, such as when carbon dioxide is evolved from some groundwaters, or if the water is rechlorinated.

Consumers detect corrosion products as follows:

* Rust from cast iron water mains is normally dark red to black and may be any size from several millimetres to a very fine sediment. Iron typically appears as orange/brown rusty stains, streaks or spots on laundry. Stains from taps also appear on baths and sinks. Iron can clog pipes and damage the internal parts of appliances. Iron can also appear after the protective zinc layer has corroded from galvanised steel pipework.
* The concentration of copper in the water can increase to levels that cause a bitter metallic taste. Blue-green water or bluish cloudy water may discharge from cold taps. There may also be a build-up of crystals or blue stains on basins or the back of the toilet bowl. In some cases the corrosion will damage household plumbing, including hot water cylinders. Copper corrosion mechanisms can be complex and the causes (apart from simple dissolution due to carbon dioxide) are generally difficult to isolate. Copper materials (including brasses and bronzes) are affected by low pH water and/or water with high sulphate contents; as a general rule, the sulphate level should not exceed twice the bicarbonate level.
* Asbestos cement pipe corrosion will lift the pH for many years and release fibres into the water. However the fibre release into drinking-water is not readily detectable by consumers, and is not a health problem. For further information, see NZWWA (2001), DWI (2002) and datasheet.

Hard water

Hard water is not common in New Zealand. Examples of major (city) supplies with fairly hard water are the groundwater supplies to Napier, Hastings, Wanganui, Gisborne’s Waipaoa River supply, and parts of Palmerston North.

Hardness may lead to the build-up of calcium carbonate in pipelines. The deposition of scale in household kettles from temporary hardness is more common. Clothes washed in hard water may look dingy and feel harsh and scratchy. Dishes and glasses may be spotted when dry. Hard water may cause a film on glass shower doors, shower walls, bathtubs, sinks, faucets, etc. More soap is needed for cleaning and hair washed in hard water may feel sticky and look dull.

Hardness can be reduced by treatment but this is unusual on large New Zealand supplies. Hard water has few of the problems with corrosion by-products experienced in soft water supplies. Hardness can be a problem in high pressure boilers.

Silica

Silica is the second most abundant mineral on Earth. High silica levels may cause post treatment precipitates that may form plaque deposits inside pipework under certain conditions. Under certain conditions it can distil across in steam generators staining (for example) vehicle windows with a milky film; otherwise its main problem is in boilers.

Temperature

As the water temperature increases, corrosion rates increase, biofilm growth rates increase, chemicals can leach more rapidly from materials used in the pipework and plumbing, tastes and odours may become more detectable, and residual chlorine dissipates more quickly. Apart from natural seasonal effects, the water temperature can increase in service reservoirs (particularly if unburied, and if the water sits there for a few days), and in water mains and service pipes that are too close to the surface (or even laid on the ground!). People generally prefer to drink cool water. Water in a low-use reservoir in Auckland has been measured at about 30°C!

Biofilms

A biofilm is a collection of organic and inorganic, living and dead material, attached to a surface. It may be a complete film, or, more commonly in water systems, it is a small patch on a pipe surface. Biofilms in drinking-water pipe networks can be responsible for a wide range of water quality and operational problems. Biofilms contribute to loss of distribution system disinfectant residuals, increased bacterial levels, reduction of dissolved oxygen, taste and odour changes, red or black water problems due to iron- or sulfate-reducing bacteria, microbial influenced corrosion, hydraulic roughness and reduced material life. Micro-organisms in biofilms can include bacteria (including coccoid [round], rod-shaped, filamentous and appendaged bacteria), fungi and higher organisms, such as nematodes, larvae and crustaceans. Although viruses and *Cryptosporidium* do not grow in a biofilm, they can attach to biofilms after a contamination event. See WHO (2003, Chapter 10) for further information.

Biofilms (Figure 16.6), or slimes, can become established in static areas, sediments, corrosion tubercles and storage tanks. This may occur in the network or in the customer’s pipework and hoses. The biofilm may host pathogens, general heterotrophic micro-organisms (that can reach high population densities in the summer) with uncertain health-effects, and biologically oxidised precipitates of substances such as iron and manganese, and may lead to taste and odour. Where anaerobic activity develops, odorous sulphur compounds such as hydrogen sulphide can be produced. Biofilms are therefore very undesirable; they can even affect the flow.

Where nutrient levels are very low and the water is chemically stable, biofilms should only occur as a result of inadequate chlorine residual. However, if significant biofilms develop on pipe walls, then even a high chlorine residual will not effectively penetrate the biofilm. In these cases it will be necessary to flush the lines regularly at high velocity to shear off the biofilm and apply chlorine at higher concentrations. The pH value also is important in dislodging biofilm as detachment can occur more rapidly at higher pH values.

In extreme cases, air scouring, mechanical scouring (pigging) or swabbing may be needed to remove the biofilm; see WSTB (2006) for more details. WRF (2015b) provides an in depth discussion on the removal of manganese from water mains.

Figure 16.6: Structure of a biofilm



In the longer term, the growth of biofilms in corrosion tubercles, etc can be reduced by the manipulation of water chemistry to reduce corrosivity. Microbial nutrients should be limited as far as possible. Ammonia can be a marked contributor to biofilms, partly due to its reaction with chlorine. Organic carbon, nitrogen, phosphorus, sulphur compounds, trace metals and salts can all contribute to biofilm growth.

Most information about the microbiology of drinking water is obtained by examining water samples taken from taps. This type of monitoring is not representative of attached microbial communities, and it is known that biofilms represent more than 95 percent of the biomass in the distribution system. Extensive biofilms can exist even in supplies that have very low HPC or coliform levels in tap water. This can be because the biofilm does not readily slough off, or because the biofilm microorganisms are difficult to culture on commonly used media. Douterelo et al (2015) describe a study of biofilm formation and composition.

WRF (2015a) describes sampling and analytical techniques for examining biofilms. Characterisation of sampled biofilms has moved beyond simple quantification of biomass and metabolic activity to high-throughput molecular methods for identifying microbial composition which do not depend on the ability to grow an organism in culture.

### Consumer complaints

Things can go wrong in any system. If they do, it is often customers who are the first to notice, so an effective way to capture information, respond to complaints, mitigate issues, and collect data so that overall service and reliability is improved should be a documented and monitored procedure. This should be covered in the water supplier’s policy statement, and addressed where applicable in more detail in the WSP. See Chapter 18: Aesthetic Considerations.

The obligations of the water supplier to customers should be laid out in a customer charter, on the supplier website, or through a similar medium. These should include response times, prioritising complaints, and where the responsibility of the water supplier stops and starts.

Staff responsible for distribution will have to:

* investigate consumer complaints within an agreed timeframe. These typically relate to water pressure, volume, seepage, leakage, taste/odour and discolouration
* perform field tests as necessary
* advise the consumer of possible solutions to the problem
* fix the problem (where this is practical and within the terms of the customer contract)
* record the complaint and subsequent action on a register so performance measures and system reliability information can be assessed
* periodically examine and analyse the list of complaints for any discernible trends that may require remedy at the system/asset management level.

Performance measures include the general consumer complaint rate, frequency of repeat callouts, the justified consumer complaint rate, the response time to consumer complaints, and recurrence frequency.

## References

American Water Works Association Research Foundation. 1996. *Internal Corrosion of Water Distribution Systems*. Denver CO: AWWA and AWWA Research Foundation.

ANSI/AWWA. 2011. *Disinfection of Water Storage Facilities*. ANSI/AWWA Standard C652-11. Denver CO: American Water Works Association.

ANSI/AWWA. 2013. *Disinfection of Water Treatment Plants*. ANSI/AWWA Standard C653-13. Denver CO: American Water Works Association.

ANSI/AWWA. 2009. *Distribution Systems Operation and Management*. ANSI/AWWA Standard G200-09. Denver CO: American Water Works Association.

ANSI/AWWA. 2005. *Disinfecting Water Mains*. ANSI/AWWA Standard C651-05. Denver CO: American Water Works Association.

AWWA. 1989. *Steel Pipe: A guide for design and installation* (4th edition). AWWA Manual M11. Denver CO: American Water Works Association.

AWWA. 1990. *Recommended Practice for Backflow Prevention and Cross-connection Control* (2nd edition). AWWA Manual M14. Denver CO: American Water Works Association.

AWWA. 1990. *Water Quality and Treatment* (4th edition). McGraw-Hill Inc.

AWWA. 1995. *Concrete Pressure Pipe* (2nd edition). AWWA Manual M9. Denver CO: American Water Works Association.

AWWA. 1996. *Fiberglass Pipe Design* (1st edition). AWWA Manual M45. Denver CO: American Water Works Association.

AWWA. 1998. *Steel Water Storage Tanks* (1st edition). AWWA Manual M42. Denver CO: American Water Works Association.

AWWA. 2001. *Rehabilitation of Water Mains* (2nd edition). AWWA Manual M28. Denver CO: American Water Works Association.

AWWA. 2002. *PVC Pipe: Design and Installation* (2nd edition). AWWA Manual M23. Denver CO: American Water Works Association.

AWWA. 2003. *Ductile-iron Pipe and Fittings* (2nd edition). AWWA Manual M41. Denver CO: American Water Works Association.

AWWA. 2005. *Water Quality in the Distribution System*. AWWA Trends in Water Series. Denver CO: American Water Works Association.

AS/NZS 4020. 2002. *Testing of Products for Use in Contact with Drinking Water*.

AS/NZS 3500.1. 2003. *Plumbing and Drainage*. Part 1 – Water Services.

BECA. 2010. Drinking Water Standards New Zealand Cost Benefit Analysis – Engineering Input. Prepared for the Ministry of Health by CH2M Beca. 103 pp. http://www.health.govt.nz/system/files/documents/publications/drinking-water-standards-nz-cost-benefit-analysis\_0.pdf.

DoE. 1990. *Effect of Water Supply Distribution Systems Survey on Organic Contaminants in Potable Water* (HET 9155). Final report to the Department of the Environment DoE 2215-M/1 Report No DWI0032. <http://www.fwr.org/dwpage4.htm>.

Douterelo I, Jackson M, Solomon C, et al. 2015. Microbial analysis of in situ biofilm formation in drinking water distribution systems: implications for monitoring and control of drinking water quality. *Applied Microbiology and Biotechnology*, DOI 10.1007/s00253-015-7155-3.

Drinking Water Inspectorate (DWI). 2011. *List of Approved Products for Use in Public Water Supply in the United Kingdom*. London: Department for Environment, Food and Rural Affairs. See [www.dwi.gov.uk](http://www.dwi.gov.uk) or <http://dwi.defra.gov.uk/drinking-water-products/approved-products/soslistcurrent.pdf> (regularly updated).

Durand ML. 2005. *Disinfectants and Plumbing Materials: Effects on sensory and chemical characteristics of drinking water*. Thesis submitted to the faculty of the Virginia Polytechnic Institute and State University in partial fulfilment of the requirements for the degree of Master of Science in Environmental Engineering. 90 pp. <http://scholar.lib.vt.edu/theses/available/etd-11302005-121845/unrestricted/ThesisMoniqueDurand2.pdf>.

Durand ML, Dietrich AM. 2007. Contributions of silane cross-linked PEX pipe to chemical/solvent odours in drinking water. *Water Science and Technol* 55(5): 153–60.

DWI. 2002. *Asbestos Cement Drinking Water Pipes and Possible Health Risks Review for DWI*. 10 pp. <http://dwi.defra.gov.uk/research/completed-research/reports/DWI70_2_135_asbestos%20cement%20pipes.pdf>.

DWI. 2002a. *Future Regulatory Parameters: Implications for the UK*. Final report for Phase 1. DWI 70/2/145. 105 pp. <http://dwi.defra.gov.uk/research/completed-research/reports/DWI70_2_145_para%20implications.pdf>.

DWI. 2007. *The Long Term Migration of Substances from In-situ Applied Epoxy Resin Coatings*. 100 pp. DWI 7369/1. <http://dwi.defra.gov.uk/research/completed-research/reports/0850.pdf>.

DWI. 2008. *A Review of Research on Pressure Fluctuations in Drinking Water Distribution Systems and Consideration and Identification of Potential Risks of such Events Occurring in UK Distribution Systems* (WT1205 / DWI 70/2/220). 52 pp. <http://dwi.defra.gov.uk/research/completed-research/reports/DWI70_2_220.pdf>.

DWI. 2011. *Investigation of Instances of Low or Negative Pressures in UK Drinking Water Systems: Final report*. Defra Ref: WT1243/DWI 70/2/245. 95 pp. <http://dwi.defra.gov.uk/research/completed-research/2000todate.htm>.

DWI. 2011a. *An Investigation of Leaching from Flexible Rising Mains Leading from Borehole Pumps*. DWI 8102/3. 175 pp. <http://dwi.defra.gov.uk/research/completed-research/2000todate.htm>.

DWI. 2015. *Effective Microbial Control Strategies for Main Breaks and Depressurization*. DWI 70/2/261. Executive summary: <http://dwi.defra.gov.uk/research/completed-research/reports/DWI70-2-261exsum.pdf>.

DWI. 2016. *Brass Fittings: A source of lead and nickel in drinking water*. Stage 3 long term testing, April 2015 to March 2016. Executive summary. UK Water Industry Research Limited. 3 pp. <http://dwi.defra.gov.uk/research/completed-research/reports/DWI70-2-309exsum.pdf>.

DWI. 2016a. *Assessing the Effect of Water Meter Installation on Exposure to Lead in Water*. Report Reference: DEFRA10511.03. 121 pp. <http://dwi.defra.gov.uk/research/completed-research/reports/DWI70-2-282.pdf>.

Edwards M. 2004. Controlling corrosion in drinking water distribution systems: a grand challenge for the 21st century. *Water Science and Technol* 49(2): 1–8.

Glaza EC, Park JK. 1992. Permeation of organic contaminants through gasketed pipe joints. *J AWWA* 84(7): 92–100.

Health Canada. 2009. *Guidance on Controlling Corrosion in Drinking Water Distribution Systems*. Water, Air and Climate Change Bureau, Healthy Environments and Consumer Safety Branch, Health Canada, Ottawa, Ontario. (Catalogue No. H128-1/09-595E). 92 pp. https://www.canada.ca/content/dam/canada/health-canada/migration/healthy-canadians/publications/healthy-living-vie-saine/water-corrosion-eau/alt/water-corrosion-eau-eng.pdf.

Holsen TM, Park JK, Jenkins D, et al. 1991. Contamination of potable water by permeation of plastic pipe. *JAWWA* 83(8): 53–6.

Kleiner Y. 1998. *Risk Factors in Water Distribution Systems*. British Columbia Water and Waste Association, 26th Annual Conference, Whistler, BC, Canada.

Master Plumbers. 2018. *New Zealand Backflow Testing Standard: Field testing of backflow prevention devices and verification of air gaps*. Master Plumbers, Gasfitters and Drainlayers NZ Inc and Water New Zealand. 54 pp.

The New Zealand Ministry of Health’s Guides for drinking-water supplies can be accessed as Word documents on the Ministry of Health website: [http://www.health.govt.nz/water](http://www.moh.govt.nz/water) then select publications and Water Safety Plans.

Ministry of Health. *Public Health Risk Management Plan Guide PHRMP Ref: P2.* [*Treatment Processes – Water Transmission*](http://www.moh.govt.nz/moh.nsf/0/5AF58E090CF4098BCC25699600754798/%24File/WaterTransmissionV1.doc). Wellington: Ministry of Health.

Ministry of Health. *Public Health Risk Management Plan Guide PHRMP Ref: P10. Treatment Processes – Pump Operation*. Wellington: Ministry of Health.

Ministry of Health. *Public Health Risk Management Plan Guide PHRMP Ref: D1. Distribution System – Post-Treatment Storage*. Wellington: Ministry of Health.

Ministry of Health. *Public Health Risk Management Plan Guide PHRMP Ref: D2.1. Distribution System – Construction Materials*. Wellington: Ministry of Health.

Ministry of Health. *Public Health Risk Management Plan Guide PHRMP Ref: D2.2. Distribution System – System Pressure*. Wellington: Ministry of Health.

Ministry of Health. *Public Health Risk Management Plan Guide PHRMP Ref: D2.3.Distribution System – Operation*. Wellington: Ministry of Health.

Ministry of Health. *Public Health Risk Management Plan Guide PHRMP Ref: D2.4. Distribution System – Backflow Prevention*. Wellington: Ministry of Health.

Ministry of Health/Otago Polytechnic. 2002. *National Diploma in Drinking-Water Assessment. Tutor Notes and Home Assignment for Unit Standard 18458 – Drinking Water Supply Reticulation Systems*. Wellington: Ministry of Health.

Ministry of Health/Otago Polytechnic. 2002. *National Diploma in Drinking Water Assessment. Tutor Notes and Home Assignment for Unit Standard 18459 – Describe Drinking Water Reticulation System Management and Management of Critical Points*. Wellington: Ministry of Health.

Ministry of Health. 2005. *Drinking-water Standards for New Zealand* (revised 2008). Wellington: Ministry of Health.

New Zealand Building Act (BA). 2004. *New Zealand Building Code* (Clause G12/AS1). Approved document for *NZ Building Code, Water Supplies*, Clause G12 (2nd edition), 2001. Building Industry Authority. See <http://www.dbh.govt.nz/UserFiles/File/Publications/Building/Compliance-documents/G12-water-supplies-3rd-edition-amendment-8-rp.pdf>.

NSF International, 148 Avenue. Grandchamp 1150, Brussels, Belgium. Email: brussels@nsf.org. Tel: +32 2 7713654. Or look at <http://www.nsf.org/>.

NZWWA. 2001. *New Zealand Asbestos Cement Water Main Manual*. Wellington: New Zealand Water and Wastes Association.

NZWWA. 2002. *Benchmarking of Water Losses in New Zealand*. Wellington: New Zealand Water and Wastes Association.

NZWWA. 2006. *Backflow Prevention for Drinking Water Suppliers, Code of Practice*. Wellington: Backflow Special Interest Group, New Zealand Water and Wastes Association. Since revised, see:

NZWWA. 2013. *Boundary Backflow Prevention for Drinking Water Suppliers*. 41 pp. Wellington: New Zealand Water and Wastes Association[. http://www.waternz.org.nz](file:///C%3A/Users/ROdean/AppData/Local/Microsoft/Windows/AppData/AppData/Local/Microsoft/Windows/Temporary%20Internet%20Files/AppData/Local/Microsoft/Windows/Temporary%20Internet%20Files/Content.Word/.%20%20http%3A/www.waternz.org.nz).

Sadiki AI. 1998. A study of organotin level in Canadian drinking water distributed through PVC pipes. *Chemosphere* 38(7): 1541–8.

Säve-Söderbergh M, Bylund J, Malm A, et al. 2017. Gastrointestinal illness linked to incidents in drinking water distribution networks in Sweden. *Water Research* 122: 503–11.

Skjevrak I, Due A, Gjerstad KO, et al. 2003. Volatile organic components migrating from plastic pipes (HDPE, PEX and PVC) into drinking water. *Wat Res* 37(8): 1912–20.

Thompson C, Jenkins P. 1987. *Review of Water Industry Plastic Pipe Practices*. Denver CO: AWWARF.

Tomboulian P, Schweitzer L, Mullin K, et al. 2004. Materials used in drinking water distribution systems: contribution to taste-and-odor. *Water Science and Technology* 49(9): 219–26. Available on the Internet via <http://www2.oakland.edu/chemistry/faculty.cfm?ID=4616>.

USEPA. 2002. *Permeation and Leaching*. Prepared for US Environmental Protection Agency, Office of Ground Water and Drinking Water, Standards and Risk Management Division, Washington DC. Prepared by AWWA, with assistance from Economic and Engineering Services, Inc. The paper is available at the TCR website at: <http://water.epa.gov/lawsregs/rulesregs/sdwa/tcr/upload/permeationandleaching.pdf>.

USEPA. 2002a. *The Potential for Health Risks from Intrusion of Contaminants into the Distribution System from Pressure Transients*. Office of Ground Water and Drinking Water Distribution System Issue Paper. By M. LeChevalier et al. 20 pp. <http://water.epa.gov/lawsregs/rulesregs/sdwa/tcr/upload/thepotentialforhealthrisksfromintrusionofcontaminants.pdf>.

USEPA. 2002b. *New or Repaired Water Mains*. Office of Ground Water and Drinking Water Distribution System Issue Paper. 15 pp. <http://water.epa.gov/lawsregs/rulesregs/sdwa/tcr/upload/neworrepairedwatermains.pdf>.

USEPA. 2003. *Cross Connection Control Manual*. EPA 816-R-03-002. 52 pp, <http://water.epa.gov/infrastructure/drinkingwater/pws/crossconnectioncontrol/crossconnectioncontrol_manual.cfm> or <http://www.epa.gov/safewater/pdfs/crossconnection/crossconnection.pdf>.

USEPA. 2006a. *Distribution System Indicators of Drinking Water Quality*. Total Coliform Rule Issue Paper. 100 pp. <http://www.epa.gov/safewater/disinfection/tcr/index.html>.

USEPA. 2006b. *Inorganic Contaminant Accumulation in Potable Water Distribution Systems*. Total Coliform Rule Issue Paper. 93 pp. <http://www.epa.gov/safewater/disinfection/tcr/index.html>.

Utting P, Taylor R, Urquhart T, et al. 1993. *Contamination, What Contamination?* Paper presented at the NZWWA Annual Conference.

Water Authorities Association. 1988. *Operational Guidelines for the Protection of Drinking Water Supplies*. United Kingdom.

*Water Supplies Protection Regulations (WSPR)*. 1961. Wellington: Ministry of Health.

Water UK. 2010. *Principles of Water Supply Hygiene Document*. Technical Guidance Notes 1–10. 17 pp. <http://www.water.org.uk/home/policy/publications/archive/drinking-water/priciples-of-water-supply-hygiene>.

WHO. 2001. *Leakage Management and Control: A best practice training manual*. WHO/SDE/WSH/01.1. World Health Organization. 169 pp. Available on the internet at: <http://www.who.int/water_sanitation_health/hygiene/om/leakage/en/index.html>.

WHO. 2003. *Heterotrophic Plate Counts and Drinking-water Safety: The significance of HPCs for water quality and the human health*. Published on behalf of World Health Organization by IWA Publishing. 271 pp. Available on the internet at: http://www.who.int/water\_sanitation\_health/dwq/hpc/en/index.html.

WHO. 2004. *Guidelines for Drinking-water Quality* (3rd edition). Geneva: World Health Organization. Available at: [www.who.int/water\_sanitation\_health/dwq/gdwq3/en/print.html](http://www.who.int/water_sanitation_health/dwq/gdwq3/en/print.html) see also the addenda.

WHO. 2004. *Safe Piped Water: Managing microbial water quality in distribution systems*. 147 pp. Available at <http://www.who.int/water_sanitation_health/dwq/924156251X/en/index.html> and then select the chapter.

WHO. 2006. *Health Aspects of Plumbing*. Published jointly by the World Health Organization and the World Plumbing Council. ISBN 92 4 156318 4. 139 pp. Available on the internet: <http://www.who.int/water_sanitation_health/publications/plumbinghealthasp/en/>.

WHO. 2011. *Guidelines for Drinking-water Quality* (4th edition). Geneva: World Health Organization. Available at: <http://www.who.int/water_sanitation_health/publications/2011/dwq_guidelines/en/index.html>.

WHO. 2011a. *WHO Technical Notes on Drinking-water, Sanitation and Hygiene in Emergencies*. <http://www.who.int/water_sanitation_health/hygiene/envsan/technotes/en/> and then select the chapter. Revised 2013: http://www.who.int/water\_sanitation\_health/publications/technotes/en/.

WHO. 2011b. *Water Safety in Buildings*. Geneva: World Health Organization. 164 pp. [www.who.int/water\_sanitation\_health/publications/en/index.html](http://www.who.int/water_sanitation_health/publications/en/index.html).

WHO. 2014. Water Safety in Distribution Systems. WHO/FWC/WSH/14.03. 147 pp. <http://www.who.int/water_sanitation_health/publications/Water_Safety_in_Distribution_System/en/>.

WHO. 2017. *Guidelines for Drinking-water Quality: Fourth edition incorporating the first Addendum*. Geneva: World Health Organization. 631 pp. <http://www.who.int/water_sanitation_health/publications/drinking-water-quality-guidelines-4-including-1st-addendum/en/>.

WRF. 2010. *Impacts of Lining Materials on Water Quality*. Water Research Foundation and Drinking Water Inspectorate. 218 pp. <http://dwi.defra.gov.uk/research/completed-research/2000todate.htm> or <http://www.waterrf.org/PublicReportLibrary/4036.pdf>.

WRF. 2015. *The Assess-and-Fix Approach: Using Non-Destructive Evaluations to Help Select Pipe Renewal Methods*. 176 pp. <http://www.waterrf.org/PublicReportLibrary/4473.pdf>.

WRF. 2015a. *Assessing Performance of Biofilm Sampling Approaches*. Water Research Foundation in conjunction with USEPA. 148 pp. <http://www.waterrf.org/PublicReportLibrary/4368.pdf>.

WRF. 2015. *Legacy of Manganese Accumulation in Water Systems*. PDF Report #4314. Water Research Foundation. 193 pp. <http://www.waterrf.org/PublicReportLibrary/4314.pdf>.

WRF. 2016. *Case Studies to Identify Occurrence, Accuracy and Causes of Reverse Flow Using Meter Systems*. November. Project Number: 4384. <http://www.waterrf.org/resources/magazine/Pages/Current-Issue.aspx>.

WRF. 2016a. *Metals Accumulation and Release within the Distribution System: Evaluation and Mitigation* [Project #4509]. Water Research Foundation. <http://www.waterrf.org/Pages/Projects.aspx?PID=4509>.

WSTB. 2005. [*Public Water Supply Distribution Systems: Assessing and reducing risks – first report*](http://www.nap.edu/catalog.php?record_id=11262). Water Science and Technology Board. 58 pp. <http://books.nap.edu/catalog.php?record_id=11262>.

WSTB. 2006. *Drinking Water Distribution Systems: Assessing and reducing risks*. Water Science and Technology Board. 404 pp. <http://www.nap.edu/catalog.php?record_id=11728>.

1. Chapter 6 includes an Appendix: Boil Water Notices. [↑](#footnote-ref-1)