

3

Design and operation of distribution networks

Kay Chambers, John Creasey and Leith Forbes

3.1 INTRODUCTION

Water distribution networks serve many purposes in addition to the provision of water for human consumption, which often accounts for less than 2% of the total volume supplied. Piped water is used for washing, sanitation, irrigation and fire fighting. Networks are designed to meet peak demands; in parts of the network this creates low-flow conditions that can contribute to the deterioration of microbial and chemical water quality. To maintain microbial quality, the network should be designed and operated to prevent ingress of contaminants, to maintain disinfectant residual concentrations within a locally predetermined range and to minimize the transit time (or age of the water after leaving the treatment works).

The issues for designing and operating a distribution network discussed in this chapter are:

- design and operation of piped networks;
- design and operation of service reservoirs;
- controlling disinfectant residuals by booster (relay) dosing;
- avoiding potential problems when mixing water sources in distribution;
- potential effects of zoning networks;
- pipe materials;
- pipe location;
- protection from cross-connections and backflow at point of delivery.

3.2 DESIGN AND OPERATION OF PIPED NETWORKS

3.2.1 Hydraulics

The purpose of a system of pipes is to supply water at adequate pressure and flow. However, pressure is lost by the action of friction at the pipe wall. The pressure loss is also dependent on the water demand, pipe length, gradient and diameter. Several established empirical equations describe the pressure–flow relationship (Webber, 1971), and these have been incorporated into network modelling software packages to facilitate their solution and use.

When designing a piped system, the aim is to ensure that there is sufficient pressure at the point of supply to provide an adequate flow to the consumer. For example, in England and Wales, water companies are required to supply water to a single property at a minimum of 10 m head of pressure at the boundary stoptap with a flow rate of 9 l/min (OFWAT, 1999). This minimum pressure increases as the number of properties supplied through a single service pipe increases.

For the purposes of maintaining microbial quality, it is important to minimize transit times and avoid low flows and pressures. These requirements have to be balanced against the practicalities of supplying water according to the location of consumers and where pipes can be laid.

Excessive capacity

The system should not have excessive capacity (which will result in long transit times) unless this excess capacity is required to meet a known increase in future demand.

Low-flow dead-ends and loops

Ideally, low-flow dead-ends and loops should be avoided, but in practice this is not always possible. Low-flow sections of dead-ends should be as short as possible. Both dead-ends and loops in the system may cause problems by

creating long residence times and sections where sediments can collect. Changes in flow direction (“tidal flows”) in loops may disturb any deposits in the pipes. Operators should be aware of these possible problematic locations and closely monitor and maintain these pipes (see Chapter 4).

Negative pressures

Situations that may give rise to negative pressures should always be avoided. Faecal organisms and culturable human viruses may be present in groundwater adjacent to a pipeline and drawn into a pipe during transient low or negative pressures (LeChevallier et al., 2003). Hydraulic models can be used to identify where, when and how negative pressures may occur. Preventative measures such as system reinforcement may then be identified and implemented. Until such measures are effective, staff responsible for the daily operation of the network should be informed of these situations and hence where, when and how contamination of the network may occur. Such situations may occur where there are:

- properties on high ground;
- remote properties at the end of long lengths of pipe;
- demands that are greater than the design demand;
- pipes of inadequate capacity (too small diameter);
- rough pipes (e.g. corroding iron pipes or pipes with a build-up of sediment);
- equipment failures (e.g. pumps and valves, see Section 3.2.2).

Appropriate pressures

Pressure at any point in the system should be maintained within a range whereby the maximum pressure avoids pipe bursts and the minimum ensures that water is supplied at adequate flow rates for all expected demands. This may require pressure boosting at strategic locations in the network (see Section 3.2.2).

Hydraulic models

If available, network models of the system should be used to check that the system will be or is operating to the required standard. Models are valuable during design and operation of a system. A model can be used to identify problems in an existing system (e.g. closed valves that should be open) by comparing modelled pressures with actual pressures in the system.

Box 3.1. A hepatitis outbreak affecting a football team.

During September and October 1969, hepatitis affected members of a football team at a college in Massachusetts, USA. Of 97 potentially exposed individuals, there was biochemical evidence that 90 were infected, of whom 32 were jaundiced, 22 were ill though not jaundiced and 36 had no symptoms. The clustering of cases suggested a common source. No cases were seen in other students on campus and the only common factor in affected individuals was attendance at the training ground. In the absence of alternative explanations, attention turned towards a possible water source at the training grounds.

The water supply to the training ground was from a municipal supply and was used for both irrigation and drinking. The training ground was at the highest point on campus, about 80 m above the lowest point. The municipal system terminated at a meter pit and from there a pipe passed along the side of two fields, terminating at a hut where the drinking-water tap was situated. Subsurface taps used to irrigate the field were located at several points along the pipe.

The water pressure in the municipal supply averaged 140 pounds per square inch (psi), though at peak demand the pressure was only 40 psi. It was noted that the pressure in the water pipe at the field was very variable and became negative when a couple of fire hydrants in the municipal supply were opened.

Further investigations found that children who lived next to the practice field had suffered infectious hepatitis four weeks earlier and that these children played in the water that collected around one of the subsurface irrigation taps. Furthermore, at about the time that the cases would have been infected there had been a fire two miles away from the training grounds, along the line of the municipal supply. The conclusion was that the water around the irrigation tap had become contaminated from the children, that water demand from the fire had led to negative pressure in the field supply and that this had drawn contaminated water into the pipework.

Source: Morse et al. (1972).

Intermittent supply

In some situations, water supplies are only available for a restricted number of hours per day or days per week. Although such systems are not desirable, they are the reality for a large proportion of the world's population. The control of water quality in intermittent supplies represents a significant challenge to water suppliers, because the risk of backflow increases significantly due to reduced pressure. The risk may be elevated in seasons with greater rainfall, where soil moisture conditions will increase the likelihood of a pressure gradient developing from the soil to the pipe. Within the supply, the most significant points of risk will be areas where pipes pass through drains or other places

where stagnant water pools may form. Water quality may also deteriorate on recharging where surges may dislodge biofilm, leading to aesthetic problems.

Intermittent systems are very common in many countries; therefore, it is important to minimize the associated health risks. As discussed in Chapter 7, understanding the system — its vulnerability and hazards that affect it — is crucial to the control of water quality. It is unlikely to be feasible to run the first charge of water to waste throughout the system, but this may be possible in selected areas of elevated risk (determined by the potential for contamination of the supply and the level of service). Control of hazards in the immediate vicinity of pipes is more important because intermittent systems are inherently vulnerable. In the longer term, the reduction of intermittence is important; in some areas this may actually be relatively easy to achieve by using or rehabilitating service reservoirs.

3.2.2 Pumps and control valves

If gravity is insufficient to supply water at an adequate pressure, then pumps need to be installed to boost the pressure. Pumps can be either permanently operational or intermittent. They can be controlled by a time-switch, pressure or a water level in a tank or reservoir. A back-up system (e.g. a standby pump) may be needed.

Control valves (e.g. pressure reducing valves, nonreturn valves and throttled valves) are designed to optimize the operation of a network with respect to pressure, water supply and energy costs. Some control valves can be controlled from a remote site. For example, a pressure-reducing valve can be controlled by the pressure at a site further downstream that is known to be the critical low-pressure point in the network. All of these control valves need to be designed correctly for their application. Regular maintenance (see Chapter 4) is a key to ensuring that water quality is not compromised. If pumps or valves fail, low or negative pressures can arise, and this can lead to ingress of contaminants into the system. The correct location and size of a pump or valve can be identified using a network-modelling software package (see Section 3.2.1). Pumps and valves should be operated to minimize surge effects (see Section 3.2.4). Other issues to be aware of are as follows.

- Double acting air valves and ball-type hydrants, which allow the ingress of air at low pressures, provide an opportunity for ingress of contaminants if the valve is submerged in its chamber. It is important to keep the chamber dry and free of debris.
- It is worthwhile installing washout valves in dead-ends to make water disposal more convenient (see Section 3.2.1).
- Nonreturn valves may be a sensible precaution on the supply inlet to premises where high back-pressures could be accidentally generated

(see Section 3.9). Potential hazards include industrial, commercial and agricultural premises, and major “domestic” institutions such as hospitals and university halls of residence that may have significant storage and internal distribution.

3.2.3 Access for maintenance

When designing a network, it is important to incorporate fixtures that can be maintained with minimal disruption to normal flow regimes, using hygienic operating and maintenance practices (see Chapter 4 for details of maintenance procedures). The following are examples of appropriate fixtures.

- Hydrants either side of a closed valve. Stagnant, dirty water can collect at dead-ends formed by closed valves. When the valve is operated, this water and any deposits can be conveyed into the network and to consumers. By flushing the hydrants, some or all of this water can be removed before operating the valve.
- By-passes for devices such as flow meters and pressure-reducing valves that allow the devices to be taken out of service for maintenance. It may also be appropriate to install a second device, so that there is always one in use while the other is maintained.
- Valve chambers that are large enough to allow maintenance and replacement and are well drained, to reduce the possibility of contaminant ingress.
- Sufficient valves to allow containment of a problem to small areas of the system. This means that pipework does not have to be completely drained in the event of a pipe break and that small parts of the network can be isolated when undertaking system modifications.
- Entry and exit points for mains cleaning.
- Disinfection injection points at critical points, for emergency disinfectant injection to maintain a disinfectant residual.

The location and depth of installation of pipelines are important, especially when sewerage systems are adjacent (see Section 3.8). In the event of a burst water pipe, the soil structure will be undermined. If a sewer is nearby there is a risk of raw sewage entering the pipe, especially if the pipe is at the same depth or lower than the sewer.

It is worth noting that trunk mains (usually ≥ 200 mm in diameter) are generally less easy to maintain than other pipes. This is because they usually have few, if any, access points and, if they are taken out of service for maintenance, then large numbers of consumers are affected. Operators need to be aware of the risks and issues associated with trunk mains in order to plan work.

3.2.4 Surge events

A surge in pressure and flow can occur when pumps are switched or when valves and hydrants are operated. Any change in flow can result in surge (e.g. pressure reducing valve hunting can cause a surge); however, the common causes are the operation of pumps, valves and hydrants. This can result in a deterioration of water quality because the surge can disturb deposits in the pipe or on the pipe wall. These operations may also cause low pressures that could allow ingress of contaminants. The risk of significant surge, and hence water quality problems, is greater in long unbranched pipes than in branched pipes, because branched pipes reduce surge.

Recommended techniques for avoiding surge effects

There are several techniques to avoid surge effects, three of which are described here.

- Place air vessels close to pumps and major valves. Air vessels are devices that have air trapped above the water. The water level changes as the pressure varies, dampening the surge event. The advantage of this system is that no power supply is needed, but the volume of air must be maintained (Wylie & Streeter, 1978).
- Control the rate of switching pumps to make the change in flow gradual, so that the network can absorb the effect of the change in flow (Wylie & Streeter, 1978).
- Operate valves and hydrants slowly. The reasoning behind this technique is the same as for control of pump switching.

As for all devices in a network, the devices associated with the above techniques need to be sized and maintained correctly. A pump at the exit of a treatment works or service reservoir (a source pump) requires an air vessel (if this is the chosen solution) to be located immediately downstream of the pump's nonreturn valve. For a pump within the network, the upstream and downstream sides may need to be protected; thus, the correctly sized air vessel would need to be placed upstream of the pump's nonreturn valve. For a valve where suppression is needed, two air vessels may be required, one either side of the valve, to protect the network.

Other events such as fire fighting, bursts and sudden increases in demand can cause surges. Air vessels can be used to counter these surge events by placing them at a range of sites, but costs and practicalities may limit their use.

Specialized software packages are available to determine the correct position and size of an air vessel, the rate of switching of a pump and rate of operations of a valve or hydrant. This is the only way to accurately plan antisurge techniques. Basic charts have been produced but these are inadequate for

networks. Wylie & Streeter (1978) give a full description of the mechanisms and analysis of surge events.

It is possible to determine an approximate minimum safe value for the time to take to switch a pump or operate a valve (WRc, 2000). The time 't' (in seconds) should be greater than $2L/a$, where 'L' (in metres) is the "characteristic" length of the network and 'a' is the wavespeed for the pipes (in metres per second). The characteristic length of the network in its simplest form is the length of pipe downstream of the source of the surge. In a complex network, it may be the sum of the pipe lengths. The constant 'a' depends on the pipe material and other factors. As a guide, 'a' equals 300–500 m/s for a plastic pipe, 1000–1300 m/s for an iron pipe and 900–1200 m/s for asbestos cement. The critical stage of moving a valve is when it is nearly closed. This is when the movement must be carried out slowly and the time 't' applies to this part of the movement.

Inadvisable techniques for avoiding surge effects

The following three methods have also been employed to relieve surge but are not recommended because the risk of ingress and contamination is too great and/or they are impractical:

- Pressure relief valves. These release water to the atmosphere to reduce pressure but cannot solve a low-pressure surge problem.
- Double acting air valves. These are the opposite of pressure relief valves, letting air into the network when the pressure drops. These valves limit low pressures but cannot alleviate high pressures.
- Surge shafts. These are towers open to the atmosphere, which are usually very tall in order to hold water to a height equivalent to the maximum pressure head. They act like air vessels.

3.2.5 Integrated operations

The operation of a network should not just be a collection of uncoordinated activities such as valve and pump operation (and maintenance activities — see Chapter 4) but should take account of the interactions between these activities. This requires an overall strategy adapted to local circumstances and applicable to all water quality issues, not just microbial quality. The activities that can be included in a strategy are numerous and may include those listed below (UKWIR, 2000a).

- Risk assessment of each activity (e.g. valve operation) before it is undertaken and identification of actions to minimize risk (see chapters 4, 5 and 7 for tools that could be used for assessments).
- Procedures for mains cleaning, mains laying, repairs and renovations (see chapters 4 and 5 for microbiological aspects of these).

- Coordination with fire fighting services on hydrant use and awareness of which areas may be at risk of loss of pressure.
- Procedures for operating valves, hydrant and other fixtures (see sections 3.2.3 and 3.2.4 on access for maintenance and prevention of surge events). Consider labelling fixtures as to their type, status and allowed operations.
- Service reservoir design, operation and maintenance requirements (see Section 3.3 and Chapter 4).
- Procedures for changing or mixing supplies in distribution (see Section 3.5).
- Optimization of water treatment (including a full cost–benefit analysis) so that water entering the network is of good quality and the potential for regrowth in the network is minimized (see Chapter 2).
- Awareness of, and collaboration with, leakage reduction teams to identify where pressure reduction may result in low pressures.
- Good record keeping so that problems can be traced and lessons learnt. An electronic record is preferable for ease of storage and access.
- Collaboration with consumer services to keep consumers fully informed of activities on the network and any emergency advice in the case of a water quality problem (e.g. issuing boil water notices).

3.3 DESIGN AND OPERATION OF SERVICE RESERVOIRS

Service reservoirs (i.e. reservoirs that store treated water) allow fluctuations in demand to be accommodated without a loss of hydraulic integrity. They can also guarantee a supply, at least for part of the day, while the inflow into the network is stopped (e.g. for maintenance of the treatment works or upstream pipe, or a contamination incident).

Service reservoirs should be covered to avoid contamination of the water from animal faeces and other pollutants. Only covered reservoirs are considered here.

Using service reservoirs can allow the water to age by several hours (or days) and the disinfectant residual to decline, particularly in areas with high ambient temperatures. Regions of stagnant water are possible if the reservoir is not designed or operated correctly, and this creates a risk of poor-quality water entering the supply if the reservoir is operated outside its usual limits. Ingress of contaminants such as animal faeces is also a possibility (e.g. through poorly closing hatches, cracks in the walls and damaged vermin proofing).

There are two extremes of mixing in reservoirs: fully mixed and plug flow. In practice, the mixing will usually be between the two extremes (WRC, 1996). Fully mixed conditions are the preferred option for service reservoirs because

the outlet disinfectant concentration with fully mixed conditions is better than that with plug flow. An exception is when disinfection is applied at the inlet for primary disinfection purposes, in which case plug flow is preferred, to allow sufficient contact time (as in the disinfection contact tank of a water treatment works).

Near fully mixed conditions are easier to achieve than near plug flow and there are fewer stagnant regions with fully mixed conditions than with an approximation to plug flow.

3.3.1 Shape and configuration

Service reservoirs can be in various forms; for example, towers and tanks (at ground level or underground). Towers provide the extra benefit of increasing pressure head to the downstream network, which is useful in flat regions. In situations where it is not critical to provide extra pressure above that provided by the geography of the land, then ground-level or underground tanks are sufficient. These can be placed on top of hills to use the natural pressure head.

The internal shape and configuration of a reservoir are major factors in maintaining water quality while the water is stored. The five subsections below describing important features of reservoirs summarize information from a report (WRc, 1996), which identifies the limitations and scope of application of these features.

Shape and dimension

As the ratio of length to breadth of a reservoir is increased, it becomes more difficult to achieve the (desirable) fully mixed condition. In the extreme case of a long, narrow reservoir, it would be necessary to place the inlet and outlet at opposite ends; the flow would then approximate to plug flow. Therefore, the reservoir should be circular or rectangular, with a low ratio of length to breadth. For new reservoirs without baffles, a length to breadth ratio of less than 2:1 is considered optimal for water quality. For existing reservoirs with a ratio greater than 2:1, it should still be possible to optimize water quality by minimizing the residence time (see Section 3.3.2) and noting the rules on inlet and depth.

Depth of water

Generally, in reservoirs without baffles, water quality is better where the average depth is greater than 3 m, because this facilitates mixing. However, in situations where a deep reservoir creates long residence times, a depth of less than 3 m may be a compromise design. A reservoir with an exceptionally large or small volume would have a different critical level, which would need to be determined for each case, using a technique such as computational fluid dynamics.

Inlet

As a guideline, in reservoirs without baffles, inlet velocities in excess of 0.1 m/s will promote the conditions desirable for optimal water quality. A turbulent jet is needed to ensure mixing. In reservoirs without baffles that meet the dimensions and depth considerations given above, there is no strong evidence for any one preferred inlet position. Inlet position is likely to be more important for cases outside the design and depth considerations given above. Computational fluid dynamic software can be used to determine the best inlet configuration (and service reservoir design generally). Positioning of inlets and outlets at opposite corners of the same wall (even if this is the shortest wall) is not detrimental to water quality in a well-mixed reservoir. Positioning of inlets and outlets closer than this should be avoided to minimize the risk of short-circuiting. In circular reservoirs, one particular inlet position (i.e. where the inlet has a horizontal flow parallel to the wall) is detrimental to water quality and should be avoided. Inlet velocity and position is less important for reservoirs with baffles, provided that the inlet is logically positioned at the beginning of the first baffle section.

Baffles

Generally, baffles should be avoided. When designing new reservoirs (that also meet the dimensional and depth ratios and inlet considerations above) the inclusion of baffles will give a worse water quality than if baffles are not used, especially where inlet flows are virtually continuous. For reservoirs with baffles, the inlet velocity and depth considerations given above would not improve water quality. However, the inclusion of compartments is worth considering (where each compartment is designed and operated as a separate service reservoir) for the operational advantage of being able to take individual compartments out of service for maintenance without affecting water supply.

Outlet

The outlet position is not critical in a well-mixed reservoir. Outlets need to be positioned on or near floor level in order to allow the full reservoir capacity to be used. Their position relative to the inlet is not as important as the above factors.

3.3.2 Flow pattern

The following aspects of flow pattern within a service reservoir may have a substantial effect on water quality (WRc, 1996).

Residence time

The factor that has the greatest overall effect on water quality is residence time, and this should be minimized to reduce both loss of disinfectant residual and the age of the water at the outlet. Minimizing residence time, within supplier or local requirements for security of supply, will improve water quality. As mentioned in Section 3.2.1, systems should not have excessive capacity unless an increase in future demand is probable.

Pumping and loss of supply

Long periods without pumping should be avoided. Short periods such as loss of inlet flow for several hours or where pumping is only at night may not cause poor water quality. What may be of concern is that such situations will cause variable disinfectant concentrations entering supply. Where intermittent pumping is unavoidable, baffles can be an advantage. In reservoirs with baffles, the variation in disinfectant during intermittent pumping is less marked. However, the need to control the disinfectant concentration should be balanced against the disadvantages of baffles (see Section 3.3.1).

Stratification

Where incoming water temperatures differ from those in the body of the reservoir, stratification can occur. This is only an issue in reservoirs with poor mixing because good mixing does not allow thermal strata to form. Stratification is undesirable because it promotes slower moving water in some parts of the reservoir, which could provide more opportunities for microbial growth.

3.3.3 General issues

Addressing the following general issues will also help maintain water quality in service reservoirs (also see Section 4.2).

Security of site

The potential for, and consequences of, contamination of the treated water in the reservoir are substantial. Service reservoirs should always be covered to prevent wildlife and people contaminating the water. Even if the reservoir is covered, all access points should be closed securely and checked regularly.

Risk assessment before operations

A risk assessment to identify potential problems and their consequences should be undertaken before any operations such as cleaning or seasonal use. Large

numbers of people may be affected downstream of the reservoir if contamination occurs.

Sampling facilities

Sampling taps should be located to provide representative samples of water entering and leaving the reservoir. Sampling pipework should be constructed of material that does not support microbial growth (see Section 3.7) and kept to a minimum practical length. It is prudent to ensure that guidance on the minimum duration time for flushing the sampling pipework is provided at the sampling location.

Records

It is important that records are kept of the water quality, inlet and outlet flow rates, operations and any other activities that affect the reservoir. This provides an auditable trail in case of an incident, as well as valuable information for improving operations.

3.4 CONTROLLING DISINFECTANT RESIDUALS BY BOOSTER (RELAY) DOSING

3.4.1 Reasons for booster dosing

A disinfectant is typically added at the end of water treatment to give a disinfectant residual to provide some protection against microbial growth and limit the effects of contamination while the water is being conveyed through the distribution system. Chapter 2 (Section 2.3.1) for a discusses options for disinfectant residuals.

A disinfectant residual is normally consumed by exposed surfaces of materials in the network, deposits in the pipes, microorganisms and chemical species in the water (UKWIR, 2000c). It may also be consumed by contaminants entering the network; for example, as a result of cross-connections or backflow. Consequently, at the ends of long networks or networks with long transit times, the disinfectant residual concentration can be zero. This by itself is not a problem if there is no contamination or growth in microorganisms that would compromise either water quality or the monitoring of microbial quality. However, many water suppliers consider it prudent to maintain a residual to the extremities of the system, which may require disinfection stations within the network, a system known as “booster” or “relay” disinfection. (Note: maintaining the network (see Chapter 4) will help to maintain a disinfectant residual throughout the network, which may obviate the need for booster dosing.)

One method for maintaining a disinfectant residual throughout the network is to ensure a high residual concentration as water leaves the treatment works. However, this may mean that consumers immediately downstream of the treatment works receive concentrations of disinfectant that are undesirable because of tastes and odours. Booster disinfection provides an alternative solution.

3.4.2 Locating booster sites

Sampling water quality within a distribution system (at consumers' taps) will identify where the disinfectant residual is inadequate. It should be borne in mind that disinfectant residual will vary during the day as the demand, and hence transit times, change.

It would be a very expensive exercise to sample in sufficient density to assess the whole of a network. This is where water quality modelling software packages are valuable. Disinfectant residuals across the whole of the network can be modelled and areas where the disinfectant is likely to be inadequate identified. These software packages are extensions of hydraulic network models (see Section 3.2.1) where processes such as disinfectant residual decay in distribution can be modelled.

The models can also be used to test the suitability of sites for disinfection stations. By running the model, it is possible to gauge what disinfectant residual is needed at the potential sites to provide sufficient residual downstream as protection against microbial regrowth, taking into account the threshold for tastes and odours. The modelling may show that a particular site cannot be used because the disinfectant dose required to give sufficient residual concentration at downstream sites will cause taste and odour problems immediately downstream of the station.

The inlets and outlets of service reservoirs are common sites for booster disinfection. There are practical advantages: reservoirs usually provide a secure site and hence the dosing equipment can be installed in a safe environment where the public cannot easily gain access. Where a station is not on the supplier's property, then security and safety are key issues. It may be that the concern over security overrides all other considerations. Sites within the distribution system where equipment can be installed (see Section 3.4.3) may also be limited in number.

3.4.3 Equipment

Several types of equipment can be used for booster disinfection (WRc, 1995). Most are designed for use at remote sites. The following points should be considered when designing a relay station.

- *Pressure.* The pressure against which the dosing equipment needs to pump will influence the type of equipment that can be used.
- *Pump capacity.* The pump needs to operate in its mid-range when delivering the required dose. The dose needs to be appropriate for the water quality at the dosing station, the flow rate and the target disinfectant residual. Laboratory tests can be used to determine the disinfectant demand of the water and thus the required dose.
- *Volumetric versus flow-proportional dosing.* Flow-proportional dosing is the preferred option because it gives better control. A flow meter will be needed if flow-proportional dosing is adopted.
- *Feedback.* Control of dosing can be improved by using feedback from a disinfectant monitor. Such a system requires an online disinfectant monitor to provide a signal to the dosing pump. If the disinfectant concentration in the water before booster dosing is variable, feedback is important to ensure that the target disinfectant concentration is reached.
- *Maintenance.* Cost and frequency of equipment maintenance will affect staffing and budget requirements.
- *Power supply.* The power supply available (e.g. battery, mains, gravity, compressed air or solar) will influence the choice of both the equipment and the siting of the station.
- *Physical size of the equipment.* The location of the dosing equipment will impact on which equipment can be used and vice versa.
- *Reliability of the equipment.* The operating environment should be specified when selecting equipment.
- *Dosing.* Duplicate dosing arrangements are needed to provide security in case of a failure.
- *Liquid versus gaseous dosing chemicals.* Safety, cost and any by-products must be taken into account when deciding whether to use liquid or gaseous dosing chemicals.
- *Telemetry for online monitoring.* Access to a telemetry system will be required.

The equipment needs to be installed and maintained correctly to ensure that the disinfectant residual is kept at the required level. The equipment used should be fitted so that the disinfectant-solution feed pipe is fixed directly into the main or enters through a dedicated inlet on the service reservoir.

3.5 AVOIDING POTENTIAL PROBLEMS WHEN MIXING WATER SOURCES IN DISTRIBUTION

There are many distribution systems where waters from two or more sources mix within the network. In most cases this has no detrimental effect on water quality; however, if waters of significantly different composition mix in the system, quality problems may occur. It is therefore prudent to investigate potential problems before introducing a new source, and take corrective action where necessary. Those issues specific to microbial quality are dealt with in Section 3.5.3.

When an additional source is introduced, problems may occur in one or more of the following three general categories:

- Long-term change in the composition of water received by an area or by consumers — Some areas will receive water that differs from the previous supply. This may cause problems with certain industrial processes, destabilise pipe deposits and biofilms, and lead to complaints about aesthetic quality from consumers.
- Daily changes in the composition of the water received by an area or by consumers — Some parts of the network may receive water from different sources at different times of the day (tidal flow). Similar issues arise as with long-term change in composition, but in this case they are due to the short-term variability of the quality. These tidal flows are very difficult to manage.
- Blending of two different waters — Consumers may receive a blend of the two waters throughout the day. The ratio between the two waters may be constant or variable. Certain ratios may have greater detrimental effects than other ratios of the same waters, and some blends may even have effects that would not arise with either of the source waters alone.

3.5.1 Modelling and planning

Network models are a valuable way of investigating the effects of mixing. In particular, they can be used to predict where mixing will take place and how these locations vary with time of day, season and system operation. These questions can be answered with a hydraulic model, but water-quality modelling software has advantages in that it allows the source of water delivered to each point in the network to be determined; also, it can predict the proportion of water from each source delivered to each point at each time. These features enable the user to consider many of the issues raised in the previous section.

Expertise in the use of water-quality models is not as widespread as expertise with hydraulic models. Interpretation is more difficult, particularly in the area where mixing takes place. The mixing boundary itself is very sensitive to

inaccuracies in the input data. The ratio of the mix at any point can also be sensitive to input values. Decisions should not be made on the assumption that results are accurate. It is prudent to carry out a sensitivity analysis and take action on the basis that a range of mixing boundaries and mixing ratios could occur in practice.

The available water-quality modelling software packages contain only limited process models. All the models handle the transport and blending of inert substances and the decay of disinfectant residual. Treatment of other parameters depends on the particular software package; however, microbiology is a particularly weak aspect of these programmes.

Laboratory testing provides an alternative to detailed modelling. Samples of the two waters can be mixed in the predicted proportions and determinations made of the relevant parameter values. Different consumers will receive different mixes and, as described above, there will usually be some error in the predicted blend. Therefore, a range of blends should be tested to determine the chemical and microbial changes that may occur and to identify the risks of introducing the new source.

It is important to realize that both the modelling and mixing tests will only predict the effects of the mixing process, not the effects related to the interactions with biofilms and other deposits in the network.

3.5.2 Introducing a new supply

Modelling and laboratory testing are described above in Section 3.5.1, which emphasises the difficulty in producing accurate values for mixed parameters. Increased vigilance during the commissioning of a new supply is therefore recommended. Increased sampling may be necessary before, during and immediately after implementation. Sample points should be concentrated at the following locations:

- near to the predicted boundary between the areas supplied by the different waters;
- in areas supplied with a blend of different waters;
- in tidal flow areas where the source of the water changes during the day.

Samples should be analysed for parameters that the predictions have shown may be problematical. Sampling frequency and duration will depend on the nature of potential problems; if destabilisation of deposits is of concern, the effects could occur after a period of several weeks if not months.

Many complaints may be about the aesthetic quality of the water. While the water is safe, the different taste or appearance may be a cause of concern to consumers. Warning the affected consumers of the intended change and reassuring them of the water quality is an effective way to reduce complaints.

Some industrial users have very specific quality requirements. Consultation with users before implementation of change may demonstrate that there is no problem, or that the user can make simple process modifications to deal with the change.

3.5.3 Potential effects of mixing waters on disinfectant residual and microbial quality

Microbial growth in a water depends on temperature, nutrient content and disinfectant concentration. In a network, it will also depend on the composition of the internal pipe surfaces, but this effect cannot be predicted and is not discussed here. The temperature and nutrient content are relatively easy to predict in the mixed water because they will be the flow-weighted average of the values in the constituent waters. Disinfectant concentration will depend on the degree of decay in the constituent waters up to the point of mixing, the type of disinfectant in the constituent waters, the blending proportions and the chemical reactions between the disinfectant species. These are affected in turn by other compositional parameters such as pH of the mixed water.

If one source has not had its disinfectant demand satisfied and another source has a disinfectant residual, the combination of the two sources may result in the disinfectant demand of the mixed water being satisfied and the disinfectant residual concentration reducing to zero. This change will most readily be observed when surface waters and groundwaters are blended (WRc, 1990).

When the constituent waters contain different types of disinfectant, various scenarios can occur on mixing. Where the two disinfectants are free chlorine and monochloramine, the reactions are complex and depend on the water composition (White, 1992).

Two of the possible effects that can occur when waters mix are described below (WRc, 1990).

- If a groundwater of good quality with a free chlorine residual of, for example, 0.2 mg/l, is mixed in equal volumes with another water with no chlorine residual but containing a relatively low concentration of ammonia (e.g. 0.02–0.04 mg/l ammonia-N), the ratio of chlorine to ammonia-N will favour the formation of dichloramine and nitrogen trichloride, both of which are ineffective disinfectants and cause taste and odour complaints.
- If the mixing of two waters produces a change in pH and the disinfectant is monochloramine, then monochloramine may convert to dichloramine. For example, at pH 8 only 5% dichloramine will be present, but at pH 7.5 the proportion would rise to 25%.

These examples emphasize the importance of undertaking laboratory mixing experiments before blending waters in distribution.

Low temperature and high disinfectant levels inhibit microbial growth, which otherwise depends on nutrient level. However, the relationships between growth and these controlling factors are not linear and it cannot be assumed that growth in a mixed water of equal proportions, for example, is midway between the growth in each of the constituent waters. Thus, a particular water may exhibit low microbial growth at low temperature and low disinfectant residual, as may another water at a higher temperature with a higher residual, but a mix of the two may support high microbial growth.

3.5.4 Changing flow conditions and existing deposits

Stable biofilms and other deposits may be disturbed by a change in flow conditions or by changes in water composition. A new source may radically change the flow pattern in parts of the network if the new point of entry is in a different location to the existing point of entry. Network modelling (see Section 3.5.1) is well suited to predicting these changes. Some pipes may have a large increase in flow rate or a change in flow direction, which may disturb deposits or strip biofilm from the pipe wall. This may have an adverse effect on the aesthetic and microbial quality of water at the consumer's tap.

Other pipes may contain water that has taken longer to reach this point than it did before the change (i.e. it is "older"). The water quality may thus be significantly different and the water may contain a higher concentration of disinfectant, leading to stripping of biofilm — a situation that can arise even if the new water entering the system is of the same quality as the existing supply.

The following changes in water composition often lead to destabilisation of deposits (WRc, 1990):

- changing from a hard (> 200 mg/l as calcium carbonate) to a very soft water (< 50 mg/l as calcium carbonate);
- a reduction in dissolved oxygen content of the conveyed water (a well-aerated supply has > 4 mg/l of oxygen);
- a substantial increase in dissolved organic content (low content is < 2 mg/l of carbon and high content is > 3 mg/l).

Although the effects of destabilised deposits are often temporary, it is recommended that networks are cleaned before a permanent change in water type or a substantial change in flow pattern (see Chapter 4).

3.6 POTENTIAL EFFECTS OF ZONING NETWORKS

3.6.1 Potential benefits

There are a number of reasons for dividing networks into zones but, essentially, the aim is to achieve greater control over the distribution of water. An example is the practice of dividing the network into “district meter areas” for leakage control purposes, where valves are closed so that a group of 1000–2000 properties is supplied through a single flow meter. Whatever the prime reason for zoning, there are potential benefits from a water quality standpoint.

- Containment of water quality incidents (e.g. contamination) is much easier if an area can be rapidly isolated. If the zone is small, then it should be possible to contain the problem in a small area.
- Zoning can reduce the extent and complexity of mixing in distribution so that more consumers are regularly supplied with the same water quality; the problems described in Section 3.5 are therefore minimized.
- Interpretation of sample analysis data is easier.

3.6.2 Potential disadvantages

Zoning can improve water quality in some parts of the network and reduce quality in others (UKWIR, 2000b). Creating a zone changes the flow pattern in the network. Some pipes will have increased flow velocity, possibly resuspending deposits, and others will have decreased flow velocity, possibly allowing deposition. The age of the water when it reaches some properties will be less and, at other points, more. At properties where the age of the water has increased substantially, water quality may deteriorate.

Although some consumers will benefit and others suffer from the change, it is possible to limit the extent of the deleterious effects by careful siting of the closed valves. Of particular concern is the creation of new dead-ends with zero flow or long lengths with very low flow. Water quality close to the closed valve can become particularly poor and there will be increased deposition from the slow moving water.

Dead-ends are particularly important when the boundary valves are opened. On these occasions, poor-quality water will be carried into the zone or into the neighbouring zone. It is good practice to clean the dead-end lengths on each side of the boundary valve before the valve is opened. Washouts installed close to the valve on each side will facilitate this process.

3.6.3 Implementing changes

Before implementation, it is important to identify risks so that, if necessary, designs can be modified, consumers informed and remedial action planned.

Network modelling is a useful tool for predicting the effect of zoning on velocities, disinfectant concentration and age of water. Where low disinfectant concentration, long times of travel or long lengths of near-stagnant water are predicted, it may be possible to improve the situation by changing the valve positions. Models can also be used to identify the effect of the design changes or remedial measures. For example, booster disinfection may be needed because zoning will lead to low concentrations in part of the network. The best site and required set point for a disinfection station can be determined using a network model (see Section 3.4 for more details on booster dosing).

It is prudent to increase sampling in the period before, during and immediately after rezoning, as for the introduction of a new supply (see Section 3.5.2).

3.7 PIPE MATERIALS

Treated water conveyed through a piped network is exposed to numerous surfaces. It is important that no materials placed in contact with the drinking-water in the network promote microbial growth or leach any contaminants into the water that can support microbial growth (see the WHO companion text *Managing the Safety of Materials and Chemicals Used in the Production and Distribution of Drinking-water*, in preparation).

A materials approval system, where materials are tested to see if they meet defined standards before they can be added to a list of approved materials, is a recommended approach. There is no universally accepted system for such approvals. Some countries have their own national approval scheme (NAS), others leave the selection of safe materials to the individual water supply organizations.

Most approval schemes are based on tests where the product is kept in contact with test water under specified test conditions. Various tests are undertaken to assess whether the material, or contaminants arising from the material, can:

- adversely affect general water quality;
- exceed permissible levels set in national standards and positive lists, etc;
- pose a health risk to consumers.

These schemes may or may not address the ability of the materials to support or promote microbial growth. Details are beyond the scope of this review but a summary of the European approval systems and the development of a harmonized European acceptance scheme is available (WRc-NSF, 2001). The USA approval systems are based on plumbing codes and standards set by the American National Standards Institution and NSF (www.nsf.org).

The condition of existing materials in the network is also important and this is addressed in Chapter 4.

3.8 PIPE LOCATION

Water mains should be installed using adequate separation from potential sources of contamination such as sewers, storm water pipes, pipes carrying reclaimed wastewater and drainage fields for septic tanks. The appropriate separation will depend on pipe material and joint type, soil conditions and space for repair (AWWARF, 2001). Local recommendations should be followed. For example, the following separation distances are recommended in certain USA standards (Great Lakes, 1997):

- a 3 m horizontal separation between water mains and sanitary sewer force mains or sewers installed in parallel;
- a 45.7 cm vertical separation for a water main crossing above or below a sewer or force main.

3.9 PROTECTION FROM CROSS-CONNECTION AND BACKFLOW AT POINT OF DELIVERY

3.9.1 Sanitary significance

Piped water supplies are vulnerable to contamination at the point of delivery to consumers, which may be domestic households, institutions or premises for commerce, agriculture and industry. At these locations, water is transferred within the property and used not only for consumption via a tap but stored in tanks or supplied to various equipment. The water supply organization has less effective control of pipework in these situations than in the main supply network. There is a potential for backflow of water from these premises into the mains network. This may be driven by high pressures generated in equipment connected to mains water supplies, or by low pressures in the mains as described previously in this chapter. A backflow event will be a sanitary problem if there is cross-connection between the potable supply and a source of contamination. A cross-connection can be defined as: “any actual or potential connection or structural arrangement between a public or private potable water system and any other source or system through which it is possible to introduce into any part of the potable system any used water, industrial fluids, gas or substance other than the intended potable water with which the potable system is supplied” (USC FCCCHR, 1993). Examples of potential sources of cross-connections include beverage dispensers, garden hose sprayers, water jetting equipment and fire sprinkling systems. Reviews of waterborne disease outbreaks in municipal systems often identify backflow events as a causative

factor. In the USA, drinking-water contamination from backflow events has caused more waterborne disease outbreaks than any other factor (Dyksen, 1997; Craun, 1981).

3.9.2 Cross-connection control

Controlling cross-connections and preventing backflow depends on factors that are largely governed by the legal aspects of water supply in a particular country. Normally, at some point on the system the responsibility for the pipework will transfer from supplier to property owner. This is where protection for the potable water supply distribution system (e.g. a backflow prevention device installed in conjunction with a stop valve and meter) may be installed if considered necessary. The location is usually in a protected but accessible place near the boundary of the consumer's property. The consumer's system downstream of this point may contain potentially hazardous cross-connections. It may be the property owner's responsibility to identify hazards and provide those individual connections with backflow prevention devices to protect the potable water system within the property. Ideally, the backflow protection devices should be registered with the water supplier and should comply with a standard procedure for assessing the hazard.

Requirements for protection from contamination of pressurized potable water systems at cross-connection points are normally set out in appropriate regulations and adopted by the local or national legislature. The water supply agency or the appropriate governing body then implements these regulations. Cross-connection regulations will typically include the following measures (AWWA, 1990; AS/NZS, 1998):

- definition of responsibilities for cross-connection control;
- identification of personnel to perform inspections;
- categorization of cross-connection hazards and appropriate devices for each level of hazard;
- inspection schedules;
- records of control devices maintained in the system;
- procedures for installing devices on new constructions;
- details of requirements for devices to prevent backflow, in terms of materials, design, performance (including air gaps and break tanks), field testing and maintenance;
- education and certification programmes for employees;
- education programmes for the public on the hazards of cross-connections and devices that can be used in the home.

Box 3.2. An outbreak of Giardiasis at a campsite.

During the summer of 1979, an estimated 1850 people became ill with diarrhoea after camping at a private campsite in Arizona. Of seven stool samples examined, six were positive for *Giardia duodenalis*. Drinking-water from a tap on the site was implicated as the cause of the outbreak following a postal questionnaire. Of 53 people who said they had drunk the water, 51 (96%) reported illness, compared to only 3 of 12 who had not drunk it (25%). There was also a significant dose response relationship between the amount of water drunk and the risk of illness.

The water system on the site had been developed over a period of six years under the management of four separate owners. Records covering the design and maintenance of the water supply system were not available. Drinking-water came from a shallow well and was pumped to a storage tank above the campsite. The campground had its own sewage system. On investigation, it was found that both the drinking-water and sewage system used pipes of the same type and colour. Both systems operated under pressure, with the pressure in the sewage system being greater than in the drinking-water system.

Although water samples had been collected for bacteriological analysis on neighbouring sites, none had been taken from the implicated site until the outbreak. Of 11 samples taken after the outbreak was detected, three had very high coliform counts. These three samples were taken from taps that had been associated with increased risk of illness in the epidemiological study.

When fluorescein dye was introduced into the sewage treatment plant, the tap water became intensely coloured. Excavation of the distribution system revealed a direct connection between the sewage and drinking-water systems. This outbreak illustrates the importance of:

- maintaining adequate records of the design and maintenance of water and sewage systems;
- using clearly different markings to indicate drinking-water and sewerage systems;
- routine microbiological monitoring of all water supply systems.

Source: Starko et al. (1986).

Typical definitions for degrees of cross-connection hazard ratings are as follows:

- *High hazard* — Any condition, device or practice that, in connection with the potable water supply system, has the potential to cause death.
- *Medium hazard* — Any condition, device or practice that, in connection with the potable water supply system, could endanger health.
- *Low hazard* — Any condition, device or practice that, in connection with the potable water supply system, would constitute a nuisance but would not endanger health or cause injury.

The type of backflow prevention device installed has to be consistent with the hazard rating.

3.9.3 Backflow prevention devices

There are various types of backflow prevention devices; those listed below are the more common.

Air gap

An air gap is the most basic protection measure where potable water can flow without any possibility of a backflow, siphon or pressurized return of used water or contaminated substance. An air gap is suitable for use in high, medium or low-hazard conditions. A simple example is the sink inlet valve or tap, with its discharge point well above the overflow level of water in the sink.

Break tank

The air gap principle is extended to create a new supply head (pressure) and, if the tank is allowed to overflow, an air gap is maintained to the water inlet. The break tank provides a separated supply system that effectively isolates the potable water supply system from a new gravity head or a source for a pumped supply. A break tank is suitable for use in high, medium or low-hazard conditions. A simple example is the float-valve controlled toilet flushing cistern.

Mechanical control valves

Mechanical control valves are subject to wear and eventual failure. An inspection and maintenance programme is usually required, with the results of the programme to be reported to the water supplier. The following are types of mechanical backflow prevention devices that are typically installed downstream of the meter or stop valve at the property boundary. (There are other types designed for special operational conditions.)

- *The dual check valve (dual CV)*. This valve is designed for use in low-hazard conditions. The device is nontestable and is typically installed in domestic or residential water services. The dual CV consists of two independently acting nonreturn valves in series, arranged to be force loaded in the closed position. Domestic or residential basic size water meters are available with a dual CV included. The combination (water meter plus dual CV) is cheaper to purchase than the two components individually.
- *The double check valve (double CV)*. This valve is designed for use in medium-hazard conditions. This is a testable device and is typically used in smaller industrial or commercial water services. The double CV consists of two independently acting nonreturn valves in series, arranged to be force loaded in the closed position. Three test taps are included on the double CV, (upstream, intermediate and downstream) to enable regular checking of the valve performance. These devices are usually designed to allow the valves to be replaced without removing the device from the pipeline assembly.
- *The double check detector assembly (DCDA)*. This assembly is also designed for use in medium-hazard conditions. This is a testable device intended for use with fire services; it allows monitoring or metering of small draw-off of water for general use within the property. The DCDA consists of a double CV or a pair of nonreturn valves, a by-pass line with isolating ball valves and test taps, water meter and secondary double CV.
- *The reduced pressure zone assembly (RPZA)*. This assembly is designed for use in high-hazard conditions. This is a testable device and is typically used in industrial water services. The RPZA consists of two independently acting nonreturn valves in series, arranged to be force loaded in the closed position; and a relief valve positioned between the nonreturn valves, force loaded to be open to the atmosphere whenever the pressure differential across the upstream nonreturn valve reduces to a specified amount. Test taps are also provided for performance checking.

3.9.4 Typical property hazard ratings

Hazard ratings for different property types are useful for designating the type of cross-connection protection required. A qualified person nominated or approved by the regulating body should assess each connection. Table 3.1 provides some typical hazard ratings by type of connection.

Table 3.1. Typical hazard ratings for different types of connection.^a

Type of connection	Hazard rating
Agricultural, horticultural and general chemical processes	High
Buildings with recirculating water air-conditioning systems	High
Factories using toxic chemicals and processing water other than potable water	High
Hospitals, mortuaries and veterinary clinics	High
Industrial or commercial cleaning processes	High
Food preparation and beverage processing plants	Medium
High rise buildings	Medium
Hotels and large apartment blocks with swimming pool	Medium
Public swimming pools	Medium
Secondary schools with laboratories	Medium
Individual residential premises (typical)	Low
Small apartment blocks (typical)	Low
Industrial or commercial buildings	As assessed

Source: AS/NZS 3500.1.2:1998

3.9.5 Field testing and maintenance of backflow protection devices

Registered air gaps and break tanks should comply with the dimensions specified in regulations. Mechanical backflow prevention devices used for high and medium hazards should comply with the manufacturing and performance requirements nominated in regulations. For high and medium-rated hazards, the dimensions and function of each installation should be independently inspected and tested for operation by a qualified person after installation. Typical regulations specify testing after maintenance or repair and regularly at intervals not exceeding 12 months.

Service connections for residential properties and smaller commercial premises usually attract a low-hazard rating, and water suppliers may not have considered backflow prevention devices an important issue for these connections. However, some service connections use a stop tap incorporating a nonreturn valve that acts as a backflow prevention device. In some cases, the connections are fitted with two stop taps, one at the water main tapping (connection) and another at the meter. These stop taps effectively represent the performance equivalent of a dual CV. The backflow protection function of these valves cannot be tested for operation without shut down and removal, which is an unlikely event. It is not unusual for many of these connections to be in service for decades without any inspection or maintenance, and it could be expected that backflow prevention would not be effective in time. Instead of stop taps, some supply systems are connected using ball valves that have no

backflow prevention capacity. The water company may rely on the meter for backflow prevention because the basic meter is designed to include at least one nonreturn valve.

Where water by measure (metered service) is used as the predominant method of payment to the water company and the meter is used to provide backflow protection, renewal of the meter will also ensure renewal of the backflow prevention device. Many governments and regulators are legislating for accuracy in measurement for public metered systems, which results in more regular meter replacement by water companies. The performance of different types of water meters can be modelled by the water company under the varied operational conditions encountered. The model includes operational costs and income received, and an economic meter renewal period can be established. Water meters containing a dual CV provide water agencies with the opportunity to replace both at a prescheduled time.

3.10 HEALTH RELATED DESIGN AND OPERATIONS CHECKLIST

Pipe network

- Set minimum pressures to prevent intrusion and provide adequate flows at all delivery points in the distribution network.
- Maintain pressure in the network within a maximum that avoids pipe breaks and a minimum that supplies adequate flow rates to meet expected demands.
- Minimize low-flow dead-ends and loops to prevent water “stagnation”.
- Do not design with excessive capacity unless required to meet a known increase in future demand.
- Avoid situations that may give rise to negative pressures. Hydraulic models can be used to identify where these may occur and to identify solutions.
- Install nonreturn valves on the supply inlet to premises where high back pressures could be accidentally generated.
- Incorporate fixtures and designs that facilitate maintenance with minimum disruption to normal flow regimes and that prevent the ingress of contaminants at low pressures.
- Prevent pressure surges by controlling the switching of pumps and the operation of the valves. Use surge analysis to plan antisurge techniques.
- Where possible, avoid the use of pressure relief valves, double acting air valves and surge shafts to relieve surge because they may allow ingress of contaminants.

- In intermittent supplies, identify particularly high-risk areas and reduce hazards. Give high priority to preventing intermittence.
- Perform risk assessments of all operational activities that may affect water quality and ensure that documented procedures are used by all those that are involved.

Service reservoirs

- Cover service reservoirs to prevent contamination.
- Ensure that all hatches and structures are secure and vermin proof.
- Ensure that sampling facilities will provide representative samples.
- Use fully-mixed flow if possible; consider the effect of shape, dimensions and inlet conditions on the residence time and flow pattern in the reservoir.
- Perform risk assessments of all operational activities that may affect water quality and ensure that documented procedures are used by all those involved.
- Keep records of all activities on, and information about, the reservoirs.

Controlling disinfectant residuals

- Use booster dosing within distribution to avoid excessive doses at the start of the network to achieve a residual at the extremities.
- Use hydraulic models to help in identifying suitable locations.
- Ensure secure location of booster equipment.
- Consider the effects of mixing different water sources in distribution, or changing the water supply, on the resulting disinfectant residuals.

Zoning networks

- Select boundaries to minimize dead-ends and water transit times, and to maintain pressures.
- Select boundaries to aid the containment of water contamination incidents and the monitoring of parameters of hygienic significance.
- Install washouts either side of boundary valves to clean out dead-end lengths before opening boundary valves.
- Consider whether deposits may be disturbed by changes in flow velocity and direction.

Materials of construction and pipe location

- Adopt a materials approval scheme that prevents the use of materials that may promote microbial growth (or may pose any other health risk to consumers).

- When installing water mains, ensure adequate separation from potential sources of contamination such as sewers, storm water pipes, pipes carrying reclaimed wastewater and drainage fields for septic tanks.

Cross-connections and backflow

- Inform the public (and plumbers) about the hazards of cross-connections, their responsibilities and the control devices that can be used in the home.
- Specify a hazard rating system and backflow prevention devices for each level of hazard.
- Adopt a policy for testing and maintenance of backflow protection devices according to hazard rating and risk.

3.11 SUMMARY

Water supply organizations should adopt network design and operating strategies that prioritize issues closely linked to water supply hygiene. In particular, such strategies should specify how the organization would:

- identify and prevent low pressures, especially negative pressures, in the system;
- prevent pressure surges in the network;
- design the network to minimize the risks of contamination during operational activities and to avoid water stagnation;
- design and operate service reservoirs to avoid contamination by ingress and to avoid stagnation;
- control disinfectant residuals in distribution systems;
- assess the effect of different supplies entering the network;
- determine the benefits and problems of zoning the network;
- select construction materials that do not promote microbial growth;
- prevent cross-connections and backflow.

3.12 REFERENCES

- AS/NZS (1998). Australian and New Zealand Standard AS/NZS 3500.1.2:1 *National plumbing and drainage code. Part 1.2: water supply — acceptable solutions.* (<http://www.standards.com.au>).
- AWWA (1990). *Manual M14: recommended practice for backflow protection and cross-connection control.* American Water Works Association, USA.
- AWWARF (2001). *Pathogen intrusion into the distribution system.* American Water Works Association Research Foundation, Denver, USA, 72.
- Craun GF (1981). Outbreaks of waterborne disease in the United States: 1971–1978. *Journal of the American Water Works Association*, 73(7):360–369.

- Dyksen J (1997). Issue paper no. 4 — Distribution system reliability. In: *Managerial assessment of water quality and system reliability*. American Water Works Association Research Foundation, Denver, USA.
- Great Lakes Upper Mississippi River Board of State Public Health and Environmental Managers (1997). *Recommended standards for water works*. Health Education Services, Albany, New York.
- LeChevallier MW et al. (2003). The potential for health risks from intrusion of contaminants into the distribution system from pressure transients. *Journal of Water and Health*, 1(1):3–14.
- Morse LJ et al. (1972). The Holy Cross College football team hepatitis outbreak. *Journal of the American Medical Association*, 219:706–708.
- OFWAT (1999). *July return — reporting requirements and definitions manual*. Office of Water Services, Birmingham, UK.
- Starko KM et al. (1986). Campers' diarrhea outbreak traced to water-sewage link. *Public Health Reports*; 101:527–31.
- UKWIR (2000a). *Operational and maintenance strategies for maintaining water quality in distribution systems*. Report 00/DW/03/12, UK Water Industry Research Limited, London.
- UKWIR (2000b). *Effect of district meter areas on water quality*. Report 00/DW/03/13, UK Water Industry Research Limited, London.
- UKWIR (2000c). *Toolboxes for maintaining and improving drinking water quality*. Report 00/DW/03/11, UK Water Industry Research Limited, London.
- USC FCCHR (1993). University of Southern California, Foundation for Cross-Connection Control and Hydraulic Research. *Manual of Cross-Connection Control, 9th Edition*. Los Angeles, California, USA.
- Webber NB (1971). *Fluid mechanics for civil engineers*. Chapman and Hall, London.
- White GC (1992). *Handbook of chlorination and alternative disinfectants*, 3rd ed. Van Nostrand Reinhold, New York.
- WRc (1990). *Aesthetic water quality problems in distribution systems. A source document for the water mains rehabilitation manual*. WRc plc, Swindon, UK.
- WRc (1995). *Final report: controlled release principles and materials for preventing microbiological failures: Part 1 — review of existing and novel technology for boosting disinfectant residual*. Report PT 1061, WRc plc, Swindon, UK.
- WRc (1996). *Final report: operation and design of potable water reservoirs*. Report PT 2018, WRc plc, Swindon, UK.
- WRc (2000). *The effects of system operation on water quality in distribution*. Report PT 2095, WRc plc, Swindon, UK.
- WRc-NSF (2001). *European approval systems. Effects of materials on water quality*, 2nd ed. WRc-NSF Ltd, Medmenham, UK.
- Wylie EB, Streeter VL (1978). *Fluid transients*, McGraw-Hill.

4

Maintenance and survey of distribution systems

Dammika Vitanage, Francis Pamminer and Tony Vourtsanis

4.1 INTRODUCTION

Previous chapters have discussed:

- design of pipework and associated facilities to prevent contamination
- system operation to maintain pressure and structural integrity
- design and operation to avoid stagnation and preserve water quality
- prevention of deposits and biofilm by good water treatment.

Succeeding chapters provide guidance on sanitary practices for repairs and construction, and advice on the effects of small animals proliferating in the network. Achieving the objectives given in each of these chapters depends on the distribution system being well maintained and in good structural condition.

© 2004 World Health Organization. *Safe Piped Water: Managing Microbial Water Quality in Piped Distribution Systems*. Edited by Richard Ainsworth. ISBN: 1 84339 039 6. Published by IWA Publishing, London, UK.