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Precautions during construction and repairs

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5.1 INTRODUCTION

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 microorganisms:

- construction of new pipework or the abandonment of existing pipework;
- renovation work using either structural or nonstructural linings, such as polyethylene slipliners or spray-on coatings;

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- 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.

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. Minimizing 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.

This chapter addresses each of these topics, with an emphasis on recent assessments of the efficacy of traditional approaches to cleaning and disinfecting water mains after construction, planned maintenance and emergency repairs. Box 5.1 provides an example of a disease outbreak associated with a broken water main.

Box 5.1. An outbreak of jaundice associated with a broken water main.

In January 1990, the staff at Rairangpur Hospital in Orisa, India noticed a sharp increase in the number of patients admitted because of jaundice. A community survey was conducted to identify further cases. About a fifth of the population were contacted and 127 cases of jaundice were identified as occurring in December or January, giving an estimated size of the outbreak of 635 cases, with one death. Serological tests were negative for both hepatitis A and B, making this non-A, non-B hepatitis (presumably the outbreak was hepatitis E).

The city of Rairangpur has 15 wards, of which 9 had an intermittent piped water supply and 6 had to rely on hand pumps and dug wells. The town had no sewerage system and open-air defecation was the general practice. The distribution of cases of jaundice was strongly correlated with water source. People who used the piped supply were nine times more likely to have developed jaundice than people who used the dug wells.

On investigation, it was found that a main pipe had burst on December 1st, though this was promptly repaired. This pipe supplied water to the five wards with the highest attack rates. This example illustrates the importance of sanitary conditions in the vicinity of water mains undergoing repair and maintenance.

Source: Bora et al.(1993).

As for other aspects of water supply hygiene, it is important that procedures are developed for local circumstances and are incorporated in national codes of practice, and in training and instructions for waterworks staff. The national codes of practice should also be reviewed regularly in the light of local performance and international technical developments.

5.2 PRECAUTIONARY WORKING PRACTICES

Typical guidance concerning hygienic working practices usually includes general advice on prevention measures. The following advice has been abstracted from two sets of guidelines (Water UK, 1998; AWWA, 1999).

- When working with pipes and fittings on site, ensure that they are protected from contamination by storing off the ground, capping the ends of pipes and liners, and keeping fittings in wrappings until the time of use (see Box 5.2).
- Ensure that the open ends of pipes in trenches are plugged and watertight when not being worked on or when there is a risk of the trench flooding.
- Excavate trenches to below the pipe level to provide a sump, and keep as dry as possible to prevent water entering a pipe or fitting.
- Ensure that sealing materials and lubricants are clean and certified as suitable for contact with potable water supplies.
- Protect unattended trenches and engineering sites from vandals and animals.
- If a part of the distribution system has been taken out of service for an extended period, treat it as a potentially contaminated new installation. Apply the flushing, disinfection and microbiological sampling procedures that are normally applied to new installations (see below).
- If a part of the distribution system is to be abandoned, ensure that all boundaries with the live system are effectively closed with especially secure and marked valves, or are capped. Create boundaries to minimize dead legs on the live system and ensure that the location of the abandoned system is recorded for future reference.
- When planning new installations and renovation works, make sure that the plans include valves, injection and washout points to facilitate effective cleaning and disinfection of the pipework.
- As far as is practicable, if general purpose or specialized vehicles are used for water supply construction and repair duties, do not use those vehicles for other duties where contamination may be prevalent (e.g. sewerage work).

- Clearly mark equipment and materials used in contact with water supplies as intended for this purpose and protect them from direct contamination with sewage or sewage sludge.

Box 5.2. A foxy tale.

A few months after moving into their homes, residents of a new housing estate started to complain of pieces of fur and other particles appearing in their tap water. The estate was supplied with water through a 15 cm diameter main that fed into a circular main round the estate. The diameter of the pipe tapered down to 10 cm.

The cause of the particulate material was traced to a dead fox. The fox had apparently climbed into the system during construction and, when the pipe had been charged, had become stuck at the taper. Because the estate was supplied by a loop system, the flow of water to consumers' taps was not interrupted. As the fox decayed it started to break up and at this point small pieces of rotting flesh appeared in consumers' tap water.

Microbiological analysis showed heavy contamination of the system with coliforms and *Escherichia coli*. Residents of the estate had to be evacuated while the supply and the domestic plumbing systems were thoroughly cleaned.

This example illustrates the importance of ensuring that mains pipes are kept capped at all times when they are not being directly supervised.

Source: Anonymous.

5.3 PERSONNEL

Known carriers of potentially waterborne communicable diseases should not come into contact with the distribution system of potable water supplies. The local circumstances and environment will dictate which diseases pose the greatest threats and how best to employ and monitor personnel to minimize such risks. However, certain guidance concerning good practice is universally applicable, as described below.

- Water supply activities that pose a potential contamination risk should be defined and given a clear descriptive name. For example, in the United Kingdom, such activities are referred to as "restricted operations" and this terminology is used below.
- Employees and contractors involved in restricted operations should be trained in the hygienic implications of their work and basic hygienic practices. This training should include details of the personal symptoms that indicate a potential waterborne disease. All staff (employees and contractors) should be encouraged to report such symptoms without prejudice to their employment prospects.

- Employers should provide adequate toilet and washing facilities to maintain personal hygiene. Wastes from portable or temporary arrangements should be disposed of without risk to water supplies or the environment.
- A medical officer should review the suitability of individuals for restricted operations at regular intervals. This may involve the use of questionnaires.

5.4 CLEANING AND DISINFECTION PROCEDURES

Before putting into service a new, repaired, rehabilitated or modified water main carrying potable water, the main must first be cleaned, disinfected, flushed and sampled to ensure that it is free from contamination. Each stage is important, but the emergence of knowledge concerning the resistance of *Cryptosporidium* oocysts to high concentrations of disinfectants such as aqueous chlorine (WRc, 1988) has placed extra emphasis on the removal of all solid matter from the interior of pipes and fittings before reconnection. Furthermore, deposits left in mains may shield pathogens from the disinfectant and allow them to remain undetected during subsequent microbiological sampling. A main may appear satisfactory, but deposits may then be disturbed and contaminate the conveyed water. Chemical disinfection, even in relatively high doses, should never be considered a catch-all stage for ensuring hygienic conditions in a new or repaired distribution system; physical removal of all introduced deposits is a critical control stage. Some water suppliers recognize this by requiring that all new mains incorporate swab (usually polyurethane foam) insertion and removal points, to allow future maintenance and to swab the newly laid main before flushing and disinfection.

The presence of deposits previously formed in a main that is being repaired obviously creates problems when assessing whether contamination has occurred or whether cleaning has been effective. However, introduced material is likely to be less adhesive than indigenous deposits, and vigorous flushing and swabbing should be effective if well controlled.

5.4.1 Typical cleaning and disinfection procedures

Guidance concerning cleaning and disinfection procedures is an important component of water safety plans, as described in Chapter 7. The guidance typically differentiates between practices for new constructions and repairs. Tables 5.1 and 5.2 list advice contained in two readily available sets of guidelines (Water UK, 1998 and WAA, 1988; AWWA, 1999); they are given here for illustration.

Table 5.1. Recommended practice for new mains and inserted liners.

	Recommended practice[a]		Recommended practice[b]
1	Remove introduced material by flushing or other means (i.e. swabbing)	1	Flush main until clear.
2	Disinfect at initial free chlorine concentration of 25 mg/l for 24 hours. With chlorinated water: • achieve a residual of 10 mg/l if using continuous feed • dose at 100 mg/l of free chlorine for 3 hours if using slug feed.	2	Disinfect at initial free chlorine concentration of 20 mg/l for 16 hours or equivalent.
3	Flush until chlorine concentrations are equivalent to normal mains feed	3	Flush out disinfectant solution.
		4	Recharge with mains water for further 24 hours.
4	Take two consecutive sets of samples (at least 24 hours apart) along the main for bacteriological analysis.	5	Take samples along the main for bacteriological analysis.
5	Bring into service if samples are free of coliforms.	6	Bring into service if samples are free of coliforms, and if main contents are of acceptable appearance and free of taste and odour (minimum criteria).

Source: a, AWWA (1999); b, Water UK (1998) & WAA (1988).

Table 5.2. Recommended practice for repairs to mains.

	Recommended practice[a]		Recommended practice[b]
			Repair on live main without loss of pressure and without cutting (i.e. using repair clamp)
		1	Disinfect fracture area and fitting with solution containing 1000 mg/l of free chlorine.
		2	Return to service.
	Repair on wholly or partially dewatered mains		*Repair on cut main*
1	Disinfect cut area and fittings with 10 000 mg/l hypochlorite solution.	1	Disinfect cut area and fittings with solution containing 1000 mg/l of free chlorine.
2	Flush until no discolouration. If possible flush towards the work location from both directions.	2	Flush main section.
3	Where practical, isolate section of main and service connections, and chlorinate as for new mains (dose may be increased to 300 mg/l for 15 minutes), then flush to remove chlorine and any discolouration.	3	If possibility of internal contamination from vicinity of repair, charge main with chlorine solution (e.g. concentration of 20 mg/l for 2 hours or 50 mg/l for 30 minutes), then flush out.
4	Sample for bacteriological contamination to provide record of efficacy. Continue until two consecutive sets are negative.	4	Sample for bacteriological contamination.
5	Return to service	5	Return to service unless the potential internal contamination was from a sewer or similar high risk source. If so obtain prior written clearance (from operations scientist or similar).

Source: a, AWWA (1999); b, Water UK (1998) & WAA (1988).

In the case of mains undergoing renovation with spray-on linings (or similar) guidance is usually similar to that for a repair with potential internal contamination. However, additional flushing and testing is likely to be required to avoid unacceptable levels of chemical contaminants leaching from such linings.

5.4.2 Methods for dosing chlorine into the mains

Gaseous chlorine is not a practical option for field disinfection applications because it poses a safety risk for utility staff, contractors and the public. Calcium hypochlorite (as granules or tablets) and sodium hypochlorite solution are the normal chemicals of choice for this situation.

Quantities of calcium hypochlorite may be deposited in the main at regular intervals during construction or during a repair. The recommended quantities, spatial distribution and maximum filling velocity for the inlet water are a function of pipe internal diameter. Detailed guidelines are available (AWWA, 1999). The objective is to achieve an initial dose of 25 mg/l of free chlorine and to have a detectable chlorine residual after 24 hours. Some codes restrict the use of calcium hypochlorite to, for example, short lengths or emergency repairs to burst mains. Important limitations are:

- the need to keep the main clean and dry in a new construction to prevent premature dissolution;
- the presence of the solid hypochlorite, which precludes any preliminary flushing;
- the tendency of the dissolution process to concentrate the dense hypochlorite solution at the bottom of the pipe.

Sodium hypochlorite solution can be prepared in concentrated form and then dosed proportionally to flow into the main, or dosed in batch form if a tank is available. These solutions are corrosive and should be treated with caution. The flow can then be stopped when the main is full, or it can be continuously fed through the main to waste. The American Water Works Association standard (AWWA, 1999), which provides detailed guidance, refers to the former as the "slug method" and to the latter as the "continuous method". The slug method creates less volume of chlorinated water to be disposed of and uses less chemical; the continuous method can provide a uniform concentration of chlorine along the length of main. Recommended concentrations and contact times are summarized in Table 5.1.

Detailed practical information on the manufacture of chlorine solutions, chlorine measurement, destruction of chlorine residues in wastewater and flushing volumes is available (e.g. AWWA, 1999).

5.4.3 Practical problems

New construction work and renovation should present few problems because there is time available to plan carefully and to forewarn consumers. Also, the interior of the pipework is new or resurfaced and has a smooth bore, free of encrustation and corrosion. This assists in cleaning the pipe and should reduce chlorine consumption during the disinfection stage. However, some linings may themselves exert a chlorine demand and make it difficult to achieve target chlorine residuals. This has been observed during investigations of cement mortar linings applied in-situ (Rayner, Olliffe & Kings, 1993).

The majority of problems occur when making emergency repairs. The ability to quickly locate valves, stopcocks and washout points relies on good local knowledge or accessible records. Consumers may need to be warned and may have to move out of the buildings involved. Finding a convenient injection and washout point may require the isolation of a long length of main, especially in a rural area. Furthermore, the existing pipework may contain deposits and encrustation that consume the disinfectant.

These practical concerns have lead to a reappraisal of the effectiveness of the traditional cleaning and disinfection practices in recent years, as outlined in the next section.

5.4.4 Effectiveness of guidance for field disinfection

An underground pipe rig and field trials have been used to identify the performance of various disinfection practices and cleaning practices used in the UK (WRc, 1994). In a series of experiments, the dispersion of chlorine in small diameter mains (< 150 mm) was first investigated. The results demonstrated the poor and nonuniform dispersion of disinfectant that occurs when either solid or dissolved hypochlorite is introduced at one end of a pipe and then distributed by the incoming water used to charge the main. Dosing calcium hypochlorite tablets at the spacing recommended by the manufacturers reduced the nonuniformity of the distribution, but target doses were not achieved at some locations. As would be expected, dosing sodium hypochlorite solution into water being used to charge the main was most effective.

In the same investigation, the effects of various combinations of chlorine concentrations and contact times (with and without prior swabbing) were measured. The method of measurement was unusual in that the biofilm on a standardized area of the pipe interior was sampled and the bacteria enumerated using a heterotrophic plate count technique. Other investigations have relied on sampling the conveyed water. The experiments used either exhumed or in situ cast-iron pipes, which were tuberculated with corrosion products and contained established biofilms. The results were variable because of variation in the size of the bacterial colonies on the pipe surfaces. However, chlorine consumption was found to be more a function of the indigenous deposits than of the introduced deposits in pipes of this condition. Conventional doses and contact times reduced general bacterial numbers on the surfaces by 65–98%, although preswabbing appeared to have no beneficial effect in such circumstances. These results indicate that normal doses of chlorine are able to affect the bacterial populations on surfaces and hence provide some safeguard in case of certain pathogens entering pipes during construction and repair (although the disinfectant is ineffective against pathogens such as viruses and the oocysts of protozoa). The results also indicate the benefits of routine maintenance activities intended to keep the system free of deposits and biofilms.

Similar investigations have been undertaken to identify the performance of various disinfection and cleaning practices used in the USA (AWWARF, 1998). These investigations measured bacterial numbers in water that had been flushed through pipe rigs containing new pipes and old used pipes. In some cases, water flushed from the vicinity of mains breaks was used. The purpose was to identify bacterial numbers that occur on pipe surfaces and to study the disinfection kinetics within the water itself. The results were as follows.

- None of the water mains tested was found to have detectable total coliforms or acid-fast bacteria but all mains (including new ones) had high heterotrophic bacteria counts.
- Heterotrophic bacteria counts in used mains were variable, but were comparable to levels in new mains. Tuberculated used mains had higher counts than smooth bore used mains.
- All mains (including new ones) exhibited a significant chlorine demand.
- In all cases, regardless of material, diameter or age of pipe, using an initial chlorine residual of 25 mg/l and a contact time of 24 hours resulted in a four-log inactivation of heterotrophic bacteria. This, of course, applied to the flushed organisms, not those remaining on the pipe surfaces.

The results of the American Water Works Association Research Foundation (AWWARF) study confirmed that the recommended procedures are a conservative approach to disinfecting conventional indicator and heterotrophic microorganisms. The authors did, however, point out that disinfectant-resistant pathogens such as *Giardia* and *Cryptosporidium* had not been investigated in the same way and that this is an outstanding research requirement.

5.5 RISK ASSESSMENT AND MONITORING

The decision on when to commission a newly constructed or repaired water main depends on the risk of contamination, the risk that cleaning and disinfection will be ineffective, and the added security that can be provided by satisfactory results arising from bacteriological sampling. With repairs, these risks need to be balanced against the practicalities associated with interruptions to supply.

When undertaking new constructions, renovation work and planned repairs it is normal to have sufficient time available to follow all the recommended procedures for dealing with materials, excavations, physical cleaning and long-duration disinfection. In such cases, risks are already low and added security is provided by sampling the main at regular intervals along its length and by testing for coliform organisms (at the very least). The AWWA standard recommends that two consecutive sets of acceptable samples, taken at least 24 hours apart, should be obtained before recommissioning (AWWA, 1999). The Water UK guidelines recommend that new mains be charged with mains water for 24 hours, sampled at appropriate points and analysed for residual chlorine, coliforms, turbidity, taste, odour and appearance (Water UK, 1998). Mains that fail such tests will obviously require investigation and should be reflushed (or recleaned by some other means such as swabbing), rechlorinated and sampled until acceptable results are obtained, before commissioning the main.

Emergency repairs create obvious difficulties in comparison with planned work. Water suppliers are confronted with balancing the risks of contamination with the risks of poor sanitary conditions occurring in the absence of a mains supply. Table 5.2 summarizes the advice provided by two national codes. The important requirement is good site practice and information. If a break causes pressure loss and is near a leaking sewer or contaminated ground, then extreme caution should be exercised before recommissioning; a larger area may need to be cleaned. In such cases, the decision should be made by a suitably qualified employee of the water supplier.

Bacteriological sampling after emergency repairs may not inform the decision to return the affected pipe to service because of the delay in obtaining microbiological results. However, these samples are still important. They provide baseline data in the event of a problem developing subsequently; they also provide a record of the effectiveness of an organisation's working practices; indeed they may reveal differences in the performance of different repair crews. These data should be regularly reviewed to identify areas for improvement.

Box 5.3 (below) describes an outbreak of giardiasis associated with work on a water main.

5.6 SMALL COMMUNITY-MANAGED SYSTEMS

It is important to follow hygienic working practices during construction of community-managed piped supplies; also, the supply should be properly disinfected before commissioning. Training in good hygiene practices for repair work is essential for operators and managers of such supplies.

Box 5.3. An outbreak of giardiasis associated with work on a water main.

An outbreak of giardiasis affected residents of Bristol, England during the summer of 1985. There were 108 laboratory confirmed cases. Most of the cases were resident in an area supplied by a single reservoir and became ill during the middle two weeks of July. Epidemiological investigations showed a very strong association between illness and consumption of unboiled tap water in the affected area during the first week of July. Data from water samples taken from the reservoir and the distribution of cases suggested that contamination occurred after water had left the reservoir.

Although the exact cause of failure was not identified, the outbreak coincided with work on the implicated mains. The main had been opened on two separate occasions for a few hours. It was suggested that either this had allowed access to infected water or had allowed backflow into the mains during the pressure drop.

This outbreak demonstrates the dangers associated with work on the distribution system. The potential risks to public health should be considered before any work on the distribution system.

Source: Jephcott, Begg & Baker (1986).

Community operators and managers need to have a good understanding of where the distribution system is laid, and a diagram of the system that shows pipe location in relation to easily recognized landmarks. This is particularly important in older systems where changes in community operator or management committee may have occurred. It may be necessary for an external agency (such as a surveillance body) to ensure that this knowledge is maintained, through periodic visits.

Training of community operators should include hygienic working practices, and guidance material should be provided to the operator as a reference. This material should be simple and attractive, and should maximize the use of pictures (even in literate communities).

Simple guidance should be provided to communities regarding good hygiene during work carried out on pipes, based on the practices outlined above. These may need modification to remove those that are obviously not applicable (e.g. the use of specialized vehicles) and to include additional guidance that is appropriate.

Within small, community-managed systems, medical checks on personnel working on pipelines are often not feasible. It must therefore be emphasized to community operators and managers that people who are currently suffering from diarrhoea or who have recently had diarrhoea should not undertake work on distribution systems.

5.7 SUMMARY

The hygienic safety of repaired or constructed pipework is dependent on good working practice and the removal of all debris and water that may have entered a pipe. Disinfection, although important, is not a panacea for contaminated pipework, especially as some pathogens may be resistant.

Recent investigations of published guidelines for the cleaning and disinfection of new and repaired water mains show these to be effective when followed carefully. However, existing deposits and encrustations in water mains may consume much of the disinfectant.

Chlorination using an externally prepared solution of hypochlorite to charge the whole main gives the best dispersion of disinfectant. Introducing hypochlorite tablets or a volume of hypochlorite solution followed by charging the main is a much less effective means of uniform dispersion.

The construction and renovation of mains provides an opportunity to incorporate valves, and injection and washout points for swabs or for flushing. These will facilitate immediate cleaning and disinfection of the pipework, and will be useful in the long-term maintenance of the system.

Good hygiene is equally vital during work on the distribution system in small, community-managed water supplies. Providing proper training and simple guidance material to support safe, hygienic working practices in such supplies is essential.

5.8 REFERENCES

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