



Improving risk assessment and management in urban water supplies

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THE CURRENT APPROACH to management of microbial risks in distribution systems places a high reliance on the results of testing indicator bacteria. There is evidence of the fundamental weaknesses of sole reliance on such approaches as the number of samples taken represent a minute proportion of the water supplied and studies have demonstrated that this approach results in limited protection of consumer health (Payment, 1991).

The most effective way to ensure safety of drinking water is through adoption of quality assurance schemes that ensure that water supplies are designed, operated and maintained properly to avoid contamination from occurring. A good example of such an approach is Hazard Analysis and Critical Control Points, which has been used in the food industry (NACMACF, 1992). Shortly after codification of HACCP for the food industry, Havelaar (1994) proposed its application in the water industry and these principles have been being increasingly applied to water supply safety in developed countries (Davison et al, 2002).

WHO, through the revision of its Guidelines for Drinking-Water Quality, has recently developed a risk management tool called Water Safety Plans (WSPs) built on HACCP principles and there is guidance currently available in draft form (Davison et al, 2002). This approach builds on many of the traditional risk management tools used in the water industry, such as the multiple barrier principle and sanitary inspection, which were the original basis for water quality control developed in the early 20th Century (Helmer et al, 1999).

The purpose of WSPs is to minimise risks through identification and management of vulnerable points within a water supply which allow hazards (both microbial and chemical) to cause contamination. The vulnerability of the system is defined by its potential susceptibility to known hazards. The combination of hazard and vulnerability can be described as a hazardous event (NHMRC, 2002). Control measures must be identified that reduce the risk of hazardous events occurring and where there are particular points in a water supply where control is essential, these are termed control points. For both control measures and control points, simple means of monitoring linked directly to process control are required and thus focus on aspects such as chlorine residual, turbidity and sanitary inspection. Analysis of the microbial quality is retained, but as a means of validating and verifying performance and not as a routine tool for monitoring process compliance.

Ensuring water safety

Davison et al (2002) indicate that the delivery of safe drinking water comprises five key steps as shown below:

1. Water quality targets based on health concerns set on the basis of tolerable risk;
2. System assessment to determine whether the water supply can deliver water of a quality that meets the above targets;
3. Monitoring of the steps in the supply chain which are of particular importance in securing water safety;
4. Management plans to be taken during normal and incident conditions; including documentation and communication;
5. A system of independent surveillance that verifies that the above are operating properly.

The management plans developed by a water supplier based on a thorough system assessment and using appropriate monitoring, combined with less frequent verification constitute a WSP. Typically the health sector will play an important role in steps 1 and 5, and for the latter guidance is available for both rural and urban areas (WHO, 1997; Howard, 2002).

This paper will review current field experience in developing a WSP for the supply in Kampala, Uganda by a research team led by WEDC. This supply produces and distributes 120,000m³ per day though 866 kilometres of pipeline and is an example of a private-public partnership with all infrastructure owned by the parastatal National Water and Sewerage Corporation (NWSC), who also operate the treatment works. The distribution system is operated by a private contractor (OSUL) who have operational responsibility for control of the water supply and its quality, overseen by the Water Quality Control Department (WQCD) of NWSC.

Risk management steps in Uganda

The key to the implementation of WSPs is through gaining a thorough understanding of the water supply system. To develop this understanding, a number of stages are required as described below.

Assembling a risk management team

To guide the process of implementing a WSP, a Risk Management team was assembled to work with the researchers from WEDC. This was a multidisciplinary team

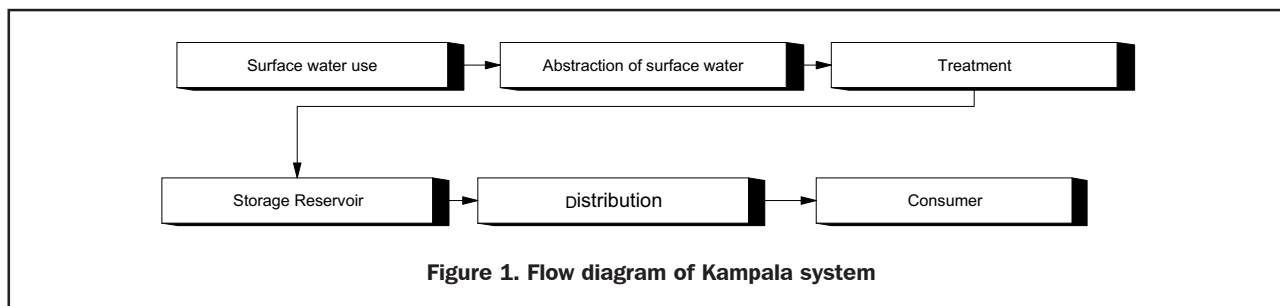


Figure 1. Flow diagram of Kampala system

comprising of managers, engineers, water quality control professionals and technicians from NWSC, OSUL and the Public Health and Environmental Engineering laboratory of Makerere University. The team is co-ordinated by the Chief Chemist of the WQCD.

Preliminary system assessment

The next stage was to carry out a preliminary assessment of the system using available data on the supply and the accumulated knowledge of the risk management team to define the vulnerability of the system and to identify control measures. One output of this preliminary assessment is a flow diagram of the system to increase the understanding of the system by the risk management team. Figure 1 outlines a flow diagram indicating the primary processes of the Kampala system.

During this process the lay out of the primary, secondary and tertiary pipelines were identified and marked on a map, with the location of major water system infrastructure such as service reservoirs and primary valves identified. This stage also included an assessment of whether the treatment works was capable of providing water to ensure that water entering the system is of adequate quality.

An evaluation of the potential vulnerability of the system to external hazards was undertaken using the flow diagram to identify components in the system likely to be at greatest risk of failure. This involved assessing aspects such as pipe material, pipe age, pipe length and condition and location of service reservoirs.

The hazards in the environment were also mapped onto the system using the GIS platform to provide an overall risk matrix including vulnerability and hazard. A risk map was developed to identify areas of particular concern. Overlain on the system risk map was an estimation of user vulnerability (a measure of socio-economic status and service

level) which provides an indication of the relative importance of different parts of the supply.

From a review of the risk map, a number of specific control measures were defined that would limit contamination and these covered actions at service reservoirs, valve boxes and in the tertiary infrastructure. Some of these control measures were defined as control points, as they were specific points within the system where contamination will have particular adverse effects. For instance, contamination at a principal valve will lead to much more widespread contamination of the system than a valve in the tertiary infrastructure.

Field assessment

The initial system assessment was “ground truthed” through a field assessment. The assessment is designed to identify inspection points with in the distribution system that will act as a surrogate for information obtained during the initial system analysis. Inspection points were identified based on the criteria outlined in table 1:

Points that fulfilled the above criteria were then located and the position provided on maps to assist inspectors in locating the inspection points during the system assessment. A total of 175 inspection points were identified in the Kampala system including service reservoirs, major valves and a randomly selected number of connections to households or public taps to assess the state of tertiary infrastructure. Each inspection point was located using a GPS to ensure they could be accurately transferred onto the risk map. At each inspection point a sanitary inspection was undertaken using a standardised questionnaire developed from previous experience in Uganda and Ghana and a review with local staff of the characteristics of each inspection point type. In addition, analysis of free chlorine

Table 1. Selection criteria for inspection points

1.	Scale of adverse health impacts
2.	Location in relation to major primary to secondary mains connection
3.	Age/Material/Length of pipe
4.	High pressure or low pressure
5.	Evidence of leakage from existing data
6.	Record of microbial contamination from existing data
7.	Proximity to hazard based on surrounding population density (as a surrogate of faecal loading)
8.	Proximity to sewers, road crossings, channels and location in low-lying areas
9.	Proximity to vulnerable area
10.	Evidence of perpetually low residual chlorine
11.	Intermittence of supply

residual, turbidity, pH and temperature were undertaken on-site.

Results from each of these points were then plotted as an overlay to the GIS platform with each single point representing an individual form of infrastructure such as a service reservoir, valve box, air valve or tank. The data were also analysed to review the frequency of reporting of different risk factors, as way of identifying appropriate limits for control measure performance.

Water safety plan

Following the ground truthing, a detailed water safety plan was developed for the Kampala system and an extract of these is shown in table 3 below. Within the WSP, for each control point in the WSP, an estimate is made of the risk as a function of the likelihood of occurrence and the degree of impact. In this example the health impact is selected from a range of options shown in table 2 below. The estimation of population affected depends on the hazard and the numbers of people that would be affected.

Within the distribution system generic control measures, performance limits and monitoring can be defined for valve boxes and tertiary infrastructure. Control points were prioritised in terms of their frequency of monitoring based on the potential impact of failure combined with an overall risk score based on pipe age, diameter, length, hazard score, population served and socio-economic status. Primary valves require weekly visits and less important valves covered by a rolling programme of inspection. The distribution control measures are also to be visited on a rolling programme using stratified sampling of block maps.

System validation

The next stage, which should be initiated in August 2002, will be to validate the WSP using a range of microbes in line with current thinking regarding the relationship between index organisms and pathogens in drinking water (Ashbolt et al, 2001). These will include *E.coli*, faecal streptococci, aeromonas, bacteriophage and *Clostridium perfringens*. Initial work on validating the risk management plan showed little contamination and suggests that the WSP is reliable.

Work is ongoing to define appropriate water quality targets using quantitative risk assessment approaches and this will be used to define both target concentrations of index organisms and the frequency with which verification is required. Additional work is also ongoing to develop ingress and propagation models for the water supply to

gain a better understanding of the system to refine the WSP and to promote more effective risk assessment.

Conclusion

WSPs are a management tool designed to reduce risks of contaminated water in domestic supplies, placing an emphasis on system process control and effective management actions. The project in Kampala has shown that these approaches can be developed for utility supplies in developing countries and offer a mechanism for more cost-effective approaches to water quality management.

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Table 2. Impact categories

Category	Impact
Catastrophic	Mortality in large population
Major	Mortality in small population
Moderate	Morbidity in large population
Minor	Morbidity in small population
Insignificant	No detectable adverse effect

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Hazard event	Cause	Risk	Control measure	Critical limits		Monitoring			Corrective action	Verification
				Target	Action	What	When	Who		
Microbial contamination of service reservoir	Birds faeces enter through vents because covers dislodged	Likely/ Catastrophic	Covers of vents remain in place	Vents covered	50% of vent support struts are damaged	Sanitary inspection	Weekly	Operations staff	Repair and replace damaged vents.	<i>E.coli</i> Faecal streptococci. Bacteriophages Sanitary inspection
Microbial contamination of service reservoir	Birds faeces enter through open inspection hatches	Likely/ Catastrophic	Inspection covers remain in place	Inspection covers locked in place	Inspection covers not in place or unlocked	Sanitary inspection Chlorine residual	Daily	Operating staff	Replace inspection cover and check chlorine consumption	<i>E.coli</i> Faecal streptococci. Bacteriophages Sanitary inspection
Ingress of contaminated water into service reservoir	Shallow water ingress through holes in reservoir; inundation by surface water of reservoir roof	Moderate/ Major	Structural integrity and drainage	Tank structure sound with no cracks; drainage channels in good condition	Drainage channels blocked; visible signs of cracks develop in tank structure	Sanitary inspection	Monthly	Operations staff	Clear drainage channels. Take tanks off-line for repairs. Flush tank and distribution before re-commissioning	<i>E.coli</i> Faecal streptococci. Bacteriophages Sanitary inspection
Ingress pathways develop due to root damage	Water ingress is facilitated by damage by trees planted on reservoir roof or grass roots from large tussocks	Likely/ Catastrophic	Structural integrity of roof; control tree growth	No trees on reservoir roof and no cracks in roof	Signs of tree growth or crack development	Sanitary inspection	Annually	Operating staff	Keep grass on reservoir well maintained and close cropped	<i>E.coli</i> Faecal streptococci. Bacteriophages Sanitary inspection
Ingress of contamination at inlet valve	Inundation of inlet valve of surface water and	Moderate/ Major	Good drainage in valve box; covers on valve box; valve packing in good condition	Valve boxes covered and do not have standing water or organic material in base; packing does not leak	Cover out of place, signs of water or material build-up; packing shows visible signs of damage	Sanitary inspection; washout drain tests	Monthly	Operating staff	Clean valve box and replace cover; clear washout drain; replace packing	<i>E.coli</i> Faecal streptococci. Bacteriophages Sanitary inspection

Annex 1. Water safety plan extract for Gun Hill service reservoir