Water Safety Plans: Book 2
Supporting Water Safety Management for Urban Piped Water Supplies in Developing Countries

Water Safety Plans: Book 2

Supporting Water Safety Management for Urban Piped Water Supplies in Developing Countries

Edited by Sam Godfrey & Guy Howard

With contributions from:
Professor T. Harpham, Dr G. Howard, Dr S. Kayaga, Dr S. Pedley, Dr R. Few, Ms K. Johal, Ms S. Tibatemwa and Mr K. Sansom

Water, Engineering and Development Centre
Loughborough University
2005

WEDC

Water, Engineering and Development Centre
Loughborough University
Leicestershire
LE11 3TU UK

A reference copy of this publication is also available online at:
http://www.lboro.ac.uk/wedc/publications/index.htm

Godfrey, S. and Howard, G., (2005)
Water Safety Plans: Book 2
Supporting Water Safety Management for
Urban Piped Water Supplies in Developing Countries
WEDC, Loughborough University, UK.

ISBN Paperback 1 84380 082 9

This document is an output from a project funded by the UK Department for International Development (DFID) for the benefit of low-income countries.
The views expressed are not necessarily those of DFID.

Designed and produced at WEDC

About the editors

Sam Godfrey (sgodfrey@unicef.org) is currently working as a Water and Environmental Sanitation Project Officer and Technical Resource Officer for water quality with UNICEF in Bhopal, Madhya Pradeshk, India. He is a Chartered Water and Environmental Manager with experience of risk assessment and management of both piped water supplies and groundwater in 15 countries in Africa, Asia and South America. He works for WEDC (the Water, Engineering and Development Centre), Loughborough University, UK where he has spent much of the last three years in Uganda and India researching appropriate risk assessment and management plans, which led to the production of these guidelines.

Dr Guy Howard (guyhoward@agni.com) is a DFID Infrastructure and Urban Development Advisor (from August 2003) and was previously a Programme Manager at WEDC, Loughborough University and Research Fellow at the Robens Centre for Public and Environmental Health, University of Surrey. He is a member of the Drinking Water Committee that oversees the revision of the WHO Guidelines for Drinking-Water Quality and is a co-author of the book Water Safety Plans: Managing drinking-water quality from catchment to consumer, which is the principal substantiation document on water safety plans for the WHO Guidelines.

Acknowledgements

The editor would like to thank those who have contributed to the development of this publication. They include:

Dr Roger Few, University of East Anglia, UK

Professor Trudy Harpham, South Bank University, London, UK

Dr Steve Pedley and Kali Johal, Robens Institute, University of Surrey, UK

Dr Sam Kayaga and Kevin Sansom, WEDC, UK

Dr Kala Vairavamoorthy, University of Loughborough, UK

Finally, the editor would like to acknowledge Sue Plummer of the WEDC Publications Office.

Who should read this book

This book has been written specifically for practitioners involved in the operation, maintenance and management of piped water supplies in urban areas in developing countries. It outlines the specialized supporting programmes that should be considered when developing Water Safety Plans (WSPs).

These practitioners include sociologists, health scientists and institutional management specialists. The book is designed to be read as a supporting document to Book 1 of the guidelines series, *Water Safety Plans: Planning Water Safety Management for Urban Piped Water Supplies in Developing Countries*. The book is written exclusively to enable water suppliers to develop WSPs without having to depend heavily on specialized external input.

How to use this book

This book is a collection of contributions from specialists in key areas, which have been identified, to aid the successful implementation of the Water Safety Plans. The book is divided into two sections:

- Section one (chapters 2-4): addresses the prerequisites required prior to establishing a Water Safety Plan; and
- Section two (chapters 5-6): focuses on the supporting programmes required to ensure effective risk management is achieved.

How does this book fit into the overall guidelines?

This book is Document 2 in the guidelines series developed for Project KaR R8029 *Improved Risk Assessment and Management for Piped Urban Water Supplies*. It provides guidance on establishing supporting programmes required for the effective development of Water Safety Plans (WSP).

Structure of the Guidelines Documents

Document 1

Water Safety Plans: Book 1
Planning water safety management for urban piped water supplies in developing countries

↓

Document 2

Water Safety Plans: Book 2
Supporting water safety management for urban piped water supplies in developing countries

↓

Document 3

Risk Based Models
Further details on Risk Based Models can be obtained from Dr Kala Vairavamoorthy, k.vairavamoorthy@lboro.ac.uk

Contents

List of boxes

List of figures

List of tables

List of acronyms

AC	Asbestos Cement
CBO	Community-Based Organization
CD	Compact Disc
CI	Cast Iron
DALY	Disability Adjusted Life Years
DI	Ductile Iron
ESRD	End-Stage Renal Disease
FGD	Focus Group Discussion
GDWQ	Guidelines for Drinking-Water Quality
GI	Galvanized Iron
GIS	Geographic Information System
GPS	Geographic Positioning System
HACCP	Hazard Assessment Critical Control Point
HUS	Haemolytic Uraemic Syndrome
ISO	International Standards Office
KAP	Knowledge, Attitudes and Practice
NGO	Non-Governmental Organization
NWSC	National Water and Sewerage Corporation
OSUL	Ondeo Services Uganda Ltd
PE	Flexible Polyethylene
QCD	Quality Control Department
QMRA	Quantitative Microbial Risk Assessment
RCC	Reinforced Cement Concrete
ROCOP	Rates of Occurance of Failure
TQM	Total Quality Management
UFW	Unaccounted for Water
WHO	World Health Organization
WQA	Water Quality Assessment
WQD	Water Quality Department
WSP	Water Safety Plan

Chapter 1

Introduction

This book outlines risk management activities designed to support the development of Water Safety Plans (WSPs). The book is written to complement *Water Safety Plans: Book 1* of the guidelines series, developed under the Department for International Development (DFID) funded research project R8029, *Improved Risk Assessment and Management of Piped Urban Water Supplies*.

Book 1, entitled *Water Safety Plans: Planning Water Safety Management for Urban Piped Water Supplies in Developing Countries*, provides guidance to operators of piped water supplies in urban areas on how to develop effective risk management plans or WSPs. It has been written exclusively to enable water suppliers to develop WSPs without having to depend heavily on specialized external input.

This book, *Water Safety Plans: Book 2*, outlines the key *prerequisites* required to successfully set up WSPs and also provides detailed guidance on how to establish key *supporting programmes*. The book is therefore divided into two sections:

- Section 1: Prerequisites to WSPs
- Section 2: Supporting programmes

Section 1 (chapters 2-4) outlines the *prerequisites* required before a WSP can be established. Chapter 2, highlights how public health risks can be estimated using *Quantitative Risk Methods*. As noted in Book 1, the successful establishment of WSPs is dependent on realistic water quality targets. This chapter provides detail on how to establish these targets. Chapter 3 identifies how to assess the *Institutional Capacity* of a water utility or management group prior to establishing a WSP. It outlines methods to assess and establish an appropriate institutional framework for the formation of a WSP. The chapter includes methods of institutional analysis and guidance which focus on the selection of appropriate institutional assessment and management tools. The final chapter in this section, Chapter 4, looks at the assessment of *Population Susceptibility*. It discusses appropriate methods for establishing WSPs based on socio-economic criteria.

Section 2 (chapters 5-6) of the book focuses on *Supporting Programmes* to WSPs. Chapter 5 outlines the appropriate methods for assessing and managing risk through the use of *Risk Maps*. This chapter details both quantitative and semi-qualitative methods for identifying points of risk within piped supplies. The final chapter, Chapter 6, provides methods to engage and interact with the end user of the WSP (i.e., the consumer). It focuses specifically on low-income communities and presents methods for assessing *Community Perceptions* of WSPs as positive means of interacting with communities in the implementation of WSPs.

Section 1

Prerequisites

Chapter 2

Quantitative risk methods

by Dr Guy Howard & Dr Steven Pedley

Introduction

This chapter reviews the use of quantitative microbial risk assessment (QMRA) as a means of assessing performance of water supplies in relation to health effects from microbial contamination in developing countries. This is related to the development of Water Safety Plans for utility supplies.

The World Health Organisation (WHO), in the revised *Guidelines for Drinking-Water Quality* (WHO, 2004) have moved towards a risk assessment and management approach to securing water safety. The guidelines outline a preventive management *Framework for Safe Drinking-Water* that comprises of five key components:

1. Health-based targets based on critical evaluation of health concerns;
2. System assessment to determine whether the water supply chain (from source through treatment to the point of consumption) as a whole can deliver water of a quality that meets the above targets;
3. Operational monitoring of the control measures in the supply chain which are of particular importance in securing drinking-water safety;
4. Management plans documenting the system assessment and monitoring and describing actions to be taken in normal operation and incident conditions, including upgrade and improvement, documentation and communication;
5. System of independent surveillance that verifies that the above are operating properly.

Within this process, health-based targets established on a tolerable level of risk are expected to be developed: health-based targets would usually be set by the health sector, taking into account, the burden of disease attributed to water, and through assessment of a full range of risks associated with water (WHO, 2003). The health-based targets that are established represent the ultimate aim of implementing a water safety framework, which includes, the WSP.

This chapter does not seek to describe how health-based targets are established, but it does focus on how risk assessments can be performed to show what level of risk to health a water supply presents. The focus of the chapter is on microbial quality as this remains the greatest risk to health from the water supply. In developing countries, these risks greatly outweigh the risks associated with chemicals; this is typified by the high rates of mortality and the disease burden derived from pathogens (Prüss et al., 2002). In other countries, such as Bangladesh, chemical risks are significant and Havelaar and Melse (2003) have provided an initial framework for assessing the disease burden for the specific case of arsenic contamination.

The first part of this chapter discusses the principles that are used to underpin QMRA. It describes how a key component, the disease burden associated with infection by a particular organism, is derived. This is essential in making subsequent judgements about the suitability of the water supply. The report provides a disease burden figure for three key pathogens that can be used in a risk assessment.

The second part of the chapter deals with how a risk assessment of a system can be implemented using case study material from Uganda. These risk assessments are designed as a means of validating current system performance, and this section discusses their use in identifying operational improvements and investment priorities.

Quantitative microbial risk assessment (QMRA)

In undertaking a quantitative risk assessment, it is essential to have a good understanding of the health outcomes from infection with particular pathogens or exposure to toxic chemicals. Exposure to a pathogen or chemical can result in a number of outcomes: these typically range from no effect (either no infection or asymptomatic infection), through mild self-limiting disease, to mortality. For pathogens, a range of sequelae can result (health effects that occur as a consequence of infection), which should where possible, be taken into account within the overall estimate of the burden of disease. These sequelae may cause hospitalisation with full recovery, hospitalisation with long-term disability, or death.

For risk assessments related to pathogen presence, a key problem in most countries is the lack of data on which to base estimates of disease impact. For instance, few countries have sufficiently reliable data to estimate the proportion of an infected population that will develop specific health end-points (an end-point is a particular extreme health effect noted for the pathogen, for example hospitalisation). There remains a significant lack of data on which to derive a disease burden estimate for specific infections. Therefore, data may have to be taken from a number of countries and sometimes used for similar pathogens where information for a specific pathogen is not available.

Furthermore, as noted by Haas et al. (1999), although risk assessments should be based on pathogen occurrence data in order to determine exposure, in the short to medium term it is likely that risk assessments will have to be based on indicator organism data. This requires several assumptions to be made regarding the relationship between pathogens and indicators. An alternative approach is not to use directly obtained data on indicator organisms, but to model 'events' within water supplies and use default figures for pathogen concentrations in water to determine theoretical exposures (Westrell et al., 2003). This approach has been used in Europe, where there is at least some data available regarding pathogen concentrations, but is not considered appropriate for developing countries where there is virtually no data. Therefore, in the examples presented below, indicator organisms were used and several assumptions were made which are described and discussed within the case studies.

In some countries, there is an increasing move towards a regulatory requirement for water suppliers to perform risk assessments on their supplies to validate their performance. In many developing countries, health-based targets may not exist or may take some time to be established. However, it is still in the water supplier's interest to determine how their system is performing in relation to potential health burdens, and therefore, undertaking a QMRA as a means of validating current performance and developing future plans should be considered.

Health-based targets

In reality, health-based targets are often translated into performance targets for water supplies: these may range from log-reductions in pathogens and toxic chemicals, through source protection measures, treatment processes and distribution management. Targets are of particular value for water suppliers and the risk assessments can be used to establish these. This may be done either through quantitative risk assessment approaches or through epidemiological studies. In the latter case, this will focus on investigations to establish the level of disease that can be attributed to a water supply. Such approaches have been used in a number of cases (Payment et al., 1991; Hellard et al., 2001; Hunter and Syed, 2001).

However, water suppliers are unlikely to have epidemiological knowledge and it may be expensive to buy in this level of expertise. Interpretation of the results for non-specialists may also prove difficult.

An alternative approach is to use quantitative risk assessment approaches. These use data based on water quality and which derive a disease burden from the water supply based on the likely risks associated with the levels of pathogens, indicator organisms or chemicals found in the water. This disease burden will be defined as a risk rather than a proven level of disease. The basis for such an approach has been described elsewhere (Regli et al., 1991; Haas et al., 1999; Havelaar and Melse, 2003) and is also outlined within the 3rd edition of the WHO *Guidelines for Drinking-Water Quality* (WHO, 2003).

Quantitative risk assessments are typically performed for individual causative agents rather than undifferentiated health effects (for example, general diarrhoea in the community). For chemicals, this would be most logically performed on those toxic chemicals known to be present in the water. For pathogens, the very wide range potentially present, the usually limited data and intermittent nature of the pathogen present, mean that the risk assessment process is often best performed on a selected range of pathogens, therefore acting as reference pathogens. A reference pathogen should be: an organism whose severity of impact and persistence in water is such that its control would provide a confidence that health risks from pathogens of a similar nature had also been controlled (WHO, 2003).

Selecting the reference pathogens for the risk assessment is the first important stage to consider. Where there are large amounts of data, such an approach would most logically be based on a review of the available clinical laboratory data of causative agents. In reality, this data may be limited or difficult to access and pathogens will be selected using expert knowledge. It is recommended that in the absence of specific information on causative agents, the use of *E.coli O157:H7*, *Cryptosporidium parvum* and rotavirus as reference pathogens will provide a reasonable basis for the risk assessments (WHO, 2003). Control of these organisms would provide reasonable confidence that all bacterial, protozoan and viral pathogens had been controlled. For each of the reference pathogens, water is a well-proven route of infection.

In undertaking a QMRA, both morbidity and mortality burdens must be considered to build a full picture of the health impact of a pathogen. The use of Disability Adjusted Life Years (DALYs) is an accepted approach to defining health burdens (Murray and Lopez, 1996). In calculating a DALY score different outcomes are allocated a severity weight between 0 (no effect) and 1 (death) to reflect the health impairment caused to an infected person. The higher the severity weight the greater the health impairment. Severity weights for many different diseases and injuries can be found in Murray and Lopez (1996).

The duration of the effect is estimated, with the years of life lost due to premature death being equal to the difference between the age of death and the average life expectancy at birth. In global assessments of health, the years of life lost or impaired are commonly calculated using the average life expectancy of Japanese women (the longest average worldwide) as a point of comparison (Murray and Lopez, 1996; Havelaar and Melse, 2003).

In the risk assessment discussed here, the years of life lost is calculated using the average life expectancy at birth for Uganda reported in the World Health Report, 2002 (WHO, 2002). This is felt to reflect more realistically the impact of diseases in Uganda. If the global life expectancy end-point was used, all diseases will emerge as having a very large impact, which while logical for global comparisons, does not add value for national decision-making because of the overall large health burden. In this case, using existing life expectancy has greater value in reflecting current conditions or if used to assess future effects by taking into account projected changes in life expectancy.

The use of national life expectancy does have a potential problem, as it distorts the size of disease burdens towards the illnesses of the very young. This is because diseases causing high levels of infant mortality will have a higher relative DALY score compared to diseases resulting in morbidity or death in adults. However, such distortion also reflects the importance of diseases causing infant deaths irrespective of the end-point, as DALY weights typically reflect mortality burdens. It is not believed therefore, that any undue distortion is introduced when the aim is to provide a consistent internal quantitative risk assessment estimate rather than an external comparison.

Establishing disease burdens for pathogens

A key component in undertaking a quantitative risk assessment of pathogens is to define what level of disease burden could be ascribed to the specific agent, as expressed in DALYs. The following sub-sections provide a description of how a disease burden for each of the identified reference pathogens can be calculated. The disease burdens that result provide an indication of the burden associated with each pathogen based on the overall range of impacts expected across a population group.

E.coli O157:H7

The major source of *E.coli O157:H7* is from animals, with cattle being the principal reservoir, but it may also occur in other species such as goats, pigs and chickens (Haas et al., 1999; WHO, 2003). *E.coli O157:H7* may be transmitted by a number of routes, but drinking-water is a well-proven route of infection, based on available outbreak data (Hunter, 2003). Havelaar and Melse (2003) developed a risk assessment based on data from The Netherlands for *E.coli O157:H7*, but noted that there was an absence of data from developing countries on which to base an estimate.

There is a lack of dose-response data for *E.coli O157:H7*, although Hunter (2003) notes that the ID50 (the number of organisms required to infect 50% of people exposed) ranges between 10^2 and 10^6, with outbreaks having occurred from doses of around 10^2 organisms (Haas et al., 2000; Strachan et al., 2000). As noted by Haas et al. (1999) in the absence of precise data for *E.coli O157:H7*, much data required for quantitative risk assessment (including the dose response) can be drawn from data available for *Shigella*, as the effect of both organisms is very similar because *E.coli O157:H7* possesses shiga-like toxins. In determining the disease burden, as expressed in DALYs, an understanding of the range of health impacts is needed. Figure 1 provides a schematic of the likely health consequences of infection by *E.coli O157:H7*.

A number of data sources have been used to establish the disease burden. For morbidity outcomes (watery diarrhoea and bloody diarrhoea), the proportion of symptomatic cases of gastroenteritis provided by Havelaar and Melse (2003) are used. Given the lack of data for developing countries regarding relationships between numbers of people developing gastro-intestinal disease in endemic situations, the figure given by Havelaar and Melse (2003) was deemed to be a reasonable assumption, particularly for the very young who can be expected to be at greatest risk.

For the mortality burden (the proportion of symptomatic cases resulting in death), the figure is calculated from data for *Shigella* infection in developing countries of 0.7% presented in a review by Kotloff et al. (1999). Some literature presents data on outbreaks of *E.coli O157:H7*, which have higher fatality rates (e.g. Cunin et al., 1999), as do some papers dealing with *Shigella* (e.g. Birmingham et al., 1997). However, the overall limited amount of data on infection suggests that such high mortality rates cannot be taken as being the norm. Havelaar and Melse (2003) estimated a mortality ratio of 0.2% for infection with *E.coli O157:H7* for The Netherlands, thus, the figure quoted by Kotloff et al. (1999) for *Shigella*

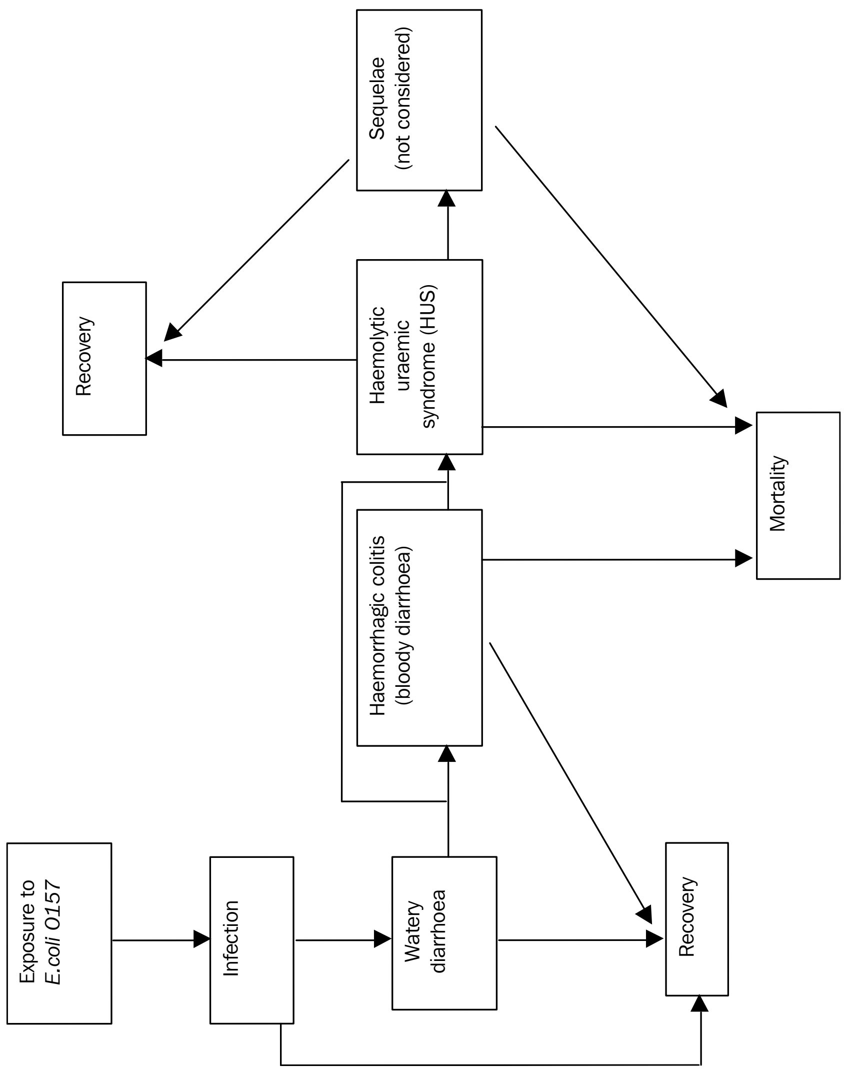


Figure 2.1. Disease outcomes from infection with *E.coli O157:H7*

represent a significantly higher mortality attribution and is reasonable in view of the greater likely incidence of mortality among children in developing countries. The mortality burden is based on an average age of death of 12 months.

A key sequela of infection by *E.coli O157:H7* is the development of haemolytic uraemic syndrome (HUS), which affects renal functioning. The estimates for HUS used are from estimates by Hunter (2003) that 10% of children infected by *E.coli O157:H7* will go on to develop HUS. This is greater than the proportion suggested by Havelaar and Melse (2003) for the general population of The Netherlands, but is used here as it is believed that infants in developing countries are likely to be at most risk of infection. The figure for death from HUS is taken from a study of *shigellosis* in Kwa-Zulu Natal (Bhimma et al., 1997). Although end-stage renal disease (ESRD) would also commonly be included within a risk assessment, as noted by Havelaar and Melse (2003), assigning a severity weight requires a complex model taking into account dialysis, transplantation grafts and other interventions, most of which will not be available in developing countries. Bhimma et al. (1997) found only 1.2% of patients with HUS developed ESRD in Kwa-Zulu Natal and although this may have an impact on the final disease burden, it is considered unrealistic to include it in the disease burden estimate.

The severity weights for the different outcomes are taken from Havelaar and Melse (2003) who used the data contained in Murray and Lopez (1996). The duration

Table 2.1. Severity, duration and disease burden for *E.coli O157:H7*

Outcomes	Severity	Duration	Disease burden (DALYs)
Watery diarrhoea	0.067	3.4 days	0.0006
Bloody diarrhoea	0.39	5.6 days	0.0060
Death from diarrhoea	1	45.4 years	45.4
HUS	0.93	15 days	0.038
Death from HUS	1	45.4	45.4

Table 2.2. Disease burden for *E.coli O157:H7*

Outcomes	Disease burden per 1000 symptomatic cases of gastroenteritis
Watery diarrhoea	1000 x 53% (watery diarrhoea) x 0.067 x 0.009 = 0.3
Bloody diarrhoea	1000 x 47% (bloody diarrhoea) x 0.39 x 0.015 = 2.8
Death from diarrhoea	1000 x 0.7% (death) x 45.4 = 317.8
Total diarrhoea only	320.9
HUS	1000 x 10% (HUS) x 0.93 x 0.041 = 3.8
Death from HUS	1000 x 1.7% (mortality) x 45.4 = 771.8
Total including HUS	1096.5

of diarrhoea is that provided by Havelaar and Melse (2003). The years of life lost is based upon death occurring at age 12 months and a life expectancy at birth in Uganda of 46.4 years (WHO, 2003).

The data described above is summarised in Table 2.1 which provides an overview of severity, duration and disease burden for the different outcomes in DALYs for *E.coli O157:H7*. Table 2.2 shows the disease burden per 1000 symptomatic cases and this can be used to provide a disease burden per case by dividing by 1000.

If only diarrhoea outcomes are used, the disease burden per case is 0.32, with the principal fraction associated with mortality. If HUS is included, the disease burden per case is 1.09, with mortality from HUS being the single most important component: the total mortality burden greatly exceeding the morbidity burden.

Cryptosporidium parvum

Cryptosporidium parvum may be found in both human and animal faeces. It is used to represent the risks associated with protozoan pathogens. Although *Cryptosporidium parvum* has been the focus of much water quality research in developed countries, there has been much less research in developing countries. More recently, there has been considerable evidence of the importance of *Cryptosporidium* infection among adults who are HIV positive or suffering from AIDS and as a cause of persistent diarrhoea among young children (Sodemann et al., 1999; Mwchari et al., 1998; Mølbak et al., 1997; Tarimo et al., 1996; Harries 1991). Water has emerged as a significant route of infection (Kelly et al., 1997).

The most common outcome of *Cryptosporidium* infection is watery diarrhoea, although to date there is no information regarding disease progression with age. Mortality can occur, with the main burden borne by immuno-compromised individuals. Despite the increasing literature dealing with infection, there remains limited quantified disease burdens, although this is available for The Netherlands, which was estimated as 1.47 DALYs per 1000 symptomatic cases (Havelaar and Melse, 2003). This estimate was based on morbidity and mortality ratios calculated using both American and Dutch data and in particular the data from the investigations of the Milwaukee incident in 1993. Hunter and Syed (2001) have suggested that the estimated size of this outbreak of 405,000 (Mackenzie et al., 1994) was greatly overstated and that the real incidence may have been between 1 and 10% of this figure. Havelaar and Melse (2003) note that if the Hunter and Syed (2001) projections are used, the mortality ratio significantly increases and the DALYs per 1000 symptomatic cases would become between 2.6 and 14.7.

Havelaar and Melse (2003) note that immune status is an issue of much greater importance when undertaking disease burden assessments for developing countries, particularly those in Africa. In The Netherlands and USA, the proportion of immuno-compromised population is relatively small and there is much greater availability of therapies that reduce the impact of opportunistic pathogens. In developed countries therefore, the position adopted in the WHO *Guidelines for Drinking-Water Quality* (WHO, 2003) that the health-based targets should be set primarily for the immuno-competent population, can be justified.

The same approach is more debatable in Africa, where the proportion of the population that is HIV positive or has AIDS is much higher. Present estimates suggests that 10% of the adult population in 16 African countries, and over 20% of adults in southern Africa are HIV positive or have AIDS. In Uganda, the prevalence rate is estimated at 8% (UNAIDS, 2003) and for the purposes of this risk assessment, the Uganda situation is taken into account. Estimating the number of people likely to die as a result as *Cryptosporidium* infection when they are HIV positive is somewhat difficult, as this is often associated with persistent diarrhoea, and death may result from a number of factors. An estimate of 10% mortality among the HIV population (equivalent to 0.8% of the total population) as suggested by Havelaar and Melse (2003) based on the data from Milwaukee is used in the absence of any other data.

To undertake the risk assessment, it is desirable that the years of life lost is based on a weighted average: of age of death by age group. However, for this simplified risk assessment, a detailed breakdown of age of death by age group for AIDS was not undertaken, in part because it would not be easy to relate this to *Cryptosporidium* infection data. Data from the UNAIDS website (UNAIDS, 2003) indicates that the majority (85%) of HIV/AIDS infections in Uganda are in the population age group 15-49 years. In calculating the years of life lost for this group, a median age of death of 30.7 years is used. The remaining 15% of HIV/AIDS infection occurs in children below 15 years and for this group a median age of 7.5 is used. The final estimate of years of life lost due to *cryptosporidiosis* was based on a weighted average using the following approach:

$(46.4 – 30.7) \times 85\% = 1334.5$

$(46.4 – 7.5) \times 15\% = 583.5$

$(1334.5 + 585.3)/100 = 19.2$ years lost.

Table 2.3. Severity, duration and disease burden for *Cryptosporidium parvum*			
Outcomes	**Severity**	**Duration**	**Burden of disease per case in DALYs**
Watery diarrhoea	0.067	7 days	0.0013
Death	1	19.2 years	19.2

Table 2.4. Disease burden for *Cryptosporidium parvum*	
Outcomes	**Disease burden (DALY) per 1000 symptomatic cases of gastroenteritis**
Watery diarrhoea	1000 x 0.067 x 0.02 = 1.34
Death	1000 x 0.8% (death) x 19.2 = 153.6
Total	154.94

The duration of watery diarrhoea was selected as 7.2 days, as reported by Havelaar and Melse (2003), as a reasonable estimate for immuno-competent individuals in Africa. It is known that persistent diarrhoea is commonly associated with *Cryptosporidium* infection among immuno-compromised individuals, but it is considered that much of the burden of this disease would be captured by the mortality burden.

The disease burdens for each outcome are summarised in Table 2.3 and Table 2.4 provides a calculation of the disease burden per 1000 symptomatic cases.

Using the data in Table 2.4, the disease burden per case would therefore be 0.15 DALYs. It should be noted that this is less than half that of diarrhoea for *E.coli O157:H7* and over 7 times lower than the disease burden including HUS. The implications of this are discussed further below. In the future, it would be worthwhile to obtain the detailed profile of HIV/AIDS infection from Uganda, in order to refine the mortality burden, as it is considered likely that the average years of life lost is in fact higher than calculated.

Rotavirus

Rotavirus is believed to account for a very large proportion of diarrhoeal disease infections in developing countries (WHO, 1996; 2003). Havelaar and Melse (2003) report that studies in the 1980s estimated the number of cases in developing countries at 125 million, with 18 million (14.4%) being severe and 873,000 deaths (a case-fatality ratio of 0.7%). These authors note, previous studies indicating that 45% of children below 2 years in developing countries carried rotavirus and that 20-40% of severe diarrhoea cases were caused by rotavirus.

Table 2.5. Severity, duration and disease burden for rotovirus			
Outcomes	**Severity**	**Duration**	**Burden of disease per case in DALYs**
Mild diarrhoea	0.10	7 days	0.002
Severe diarrhoea	0.23	7 days	0.004
Death	1	19.2 years	19.2

Table 2.6. Disease burden for rotovirus	
Outcomes	**Disease burden (DALY) per 1000 symptomatic cases of gastroenteritis**
Mild diarrhoea	1000 x 85.6% x 0.10 x 0.02 = 1.71
Severe diarrhoea	1000 x 14.4% x 0.23 x 0.02 = 0.66
Death	1000 x 0.7% (death) x 45.4 = 317.8
Total	320.17

The severity weights and duration shown below are taken from Havelaar and Melse (2003), with the years of life lost based on age of death, being 12 months. The higher severity weights allocated for rotavirus reflects, the distribution of mild and severe cases and the use of the burden of disease study weights for diarrhoea for under 5s (0.119) and for older ages (0.086-0.094). The severity, duration and disease burden for the different outcomes are shown in Table 2.5.

In a review of studies, Havelaar and Melse (2003) noted, that the case-fatality ratio for rotavirus was 0.7%, but in their calculations they used a case-fatality rate of 0.6% for developing countries to reflect what they presumed to be an improvement in treatment since the 1980s. In this risk assessment, 0.7% is retained because it was felt that the assumption of improvement would be off-set by potentially greater numbers of severe diarrhoea and the increase in likelihood of severe end-points due to HIV infection. The final disease burden is shown in Table 2.6.

This gives a DALY per case of 0.32. It should be noted that this disease burden is twice that calculated for *Cryptosporidium* and similar to *E.coli O157:H7*. In the context of developing countries, this seems to reflect the overall importance of rotavirus and bacterial pathogens.

Discussion

The result of disease burden estimates point to some interesting findings. The disease burden associated with *E.coli O157* taking into account sequelae represents a significantly greater risk than those associated with rotavirus and *Cryptosporidium*. This may not in fact be unrealistic. The complications associated with bacterial pathogens capable of producing severe sequelae should be expected to add very significantly to the disease burden above that represented by other pathogen types with few or no sequelae. This would be particularly the case in developing countries where health care systems are poorly developed and unable to provide adequate treatment for the complications of infections.

There are, however, concerns about the inclusion of the sequelae disease burden for *E.coli O157:H7* in this context. The assumptions made in the disease burden estimates of *Cryptosporidium parvum* and rotavirus do not necessarily reflect the full disease burden from each of these pathogens. In particular, the persistent diarrhoea associated with both pathogens is not considered (as equally it is not for *E.coli O157:H7*) and this, certainly for *Cryptosporidium parvum*, may lead to an overall longer duration of symptoms. At present the data is limited from Uganda to make such estimates. It is possible that the disease burden for both rotavirus and *Cryptosporidium* are under-estimated, particularly in relation to its importance in causing death among HIV positive infants. Furthermore, the lack of specific data for Uganda for HUS makes inclusion of the weighting for the sequelae problematic, as there are no real means of assessing the extent of these problems.

Therefore, within the initial risk assessments, those associated only with diarrhoea are used, as these provide a more direct comparison between the pathogens with the least probable bias in the results. This removes the very significant mortality burden associated with HUS from *E.coli O157:H7*. As there is no direct data for Uganda, inclusion of the HUS mortality burden would risk over-stating the risk from *E.coli O157:H7* and under-estimating the risks from the other pathogens.

Even when relying solely on diarrhoea risks and discounting sequelae, the risk assessment emphasises the importance of bacterial and viral pathogens in drinking-water for developing countries like Uganda. Despite the evidence of the importance of *Cryptosporidium* in Africa, this overall assessment seems realistic on the basis of reported disease burdens associated with water (WHO, 1996).

Risk assessment

The disease burdens calculated in the previous section are used to undertake a risk assessment of the water supply. Full risk assessments are very complex and use statistical distributions for many key parameters (for instance dose response) rather than point estimates. Few countries have undertaken full risk assessment exercises. Within this document, the simplified risk assessment approach contained within the 3rd edition of the WHO *Guidelines for Drinking-Water Quality* (2003) is used. The simplified risk assessment process is shown in Table 2.7.

Table 2.7. Simplified risk assessment procedure	
Raw water quality, organisms per litre (C_R)	Will probably be calculated from concentrations in standard volumes (e.g. 100ml) and may not be directly for pathogens
Treatment effect (PT)	Estimated or calculated removal of pathogens
Drinking-water quality (C_D)	C_R x (1-PT)
Consumption of unheated drinking-water (V)	Estimated or calculated
Exposure by drinking-water, organisms per litre (E)	C_D x V
Dose-response (r)	From literature
Risk of infection per day ($P_{inf,d}$)	E x r
Risk of infection per years ($P_{inf,y}$)	$P_{inf,d}$ x 365
Risk of diarrhoeal disease given infection ($P_{ill\|inf}$)	From literature
Risk of diarrhoeal disease (P_{ill})	$P_{inf,y}$ x $P_{ill\|inf}$
Disease burden (db)	Calculated in previous section
Susceptible fraction (fs)	From literature
Disease burden (DB)	P_{ill} x db x fs

To apply this framework, sources of data may come from experimentation, review of existing data or from literature. Key aspects where assumptions may be made include volume of unheated water that is consumed. In the WHO Guidelines (WHO, 2003) this is set at 1 litre per capita per day. This significantly over-estimates consumption in many developed temperate countries (for instance The Netherlands consumption is estimated at 0.25 litres per capita per day). It may underestimate consumption in tropical developing countries, although it is considered to be realistic given consumption of heated water drinks and other fluids (Howard and Bartram, 2003).

The dose response and risk of infection may both be drawn from the literature, unless specific country data are available (for instance during outbreaks). One problem with deriving local data is that in many outbreaks only attack rate is determined, which provides only numbers of symptomatic cases in the population. As those not showing symptoms will also include asymptomatic infected persons, the attack rate underestimates the infection rate. Similarly, risk of illness given infection may be drawn from the literature because if only attack rate data are available this will not account for the asymptomatic infected population. Dose-responses will typically be drawn from the literature and may in some cases require transposition of dose-responses from similar organisms.

The susceptible fraction reflects that only some of the population may be liable to acquire infection on exposure to the pathogen in water. For instance, most adults in developing countries will have acquired immunity against rotavirus and it will primarily be children that are at risk. Furthermore, this term may be used to take into account routes of infection, for instance, if multiple water source use is common then the proportion of the population susceptible may be reduced to reflect transmission from other water sources. Finally, the risk assessment is not based directly on pathogen data, but on indicator organisms, and therefore assumptions must be made regarding the relationship between the indicator and pathogen. These may vary depending on whether the indicator is being used simply to mimic behaviour (which would be more correctly described as a process indicator), as an indicator or index organism for a group of pathogens (Ashbolt et al., 2001). In the examples cited from Kampala, *Clostridium perfringens* is used as a process indicator, and *E.coli* and coliphage are used as index organisms.

Risk assessments on existing supplies can be undertaken in two ways. The simplest way is to use a literature based estimate of the likely removal of pathogens through treatment trains or source protection measures, and then assign default log removal credits for treatment processes present. This means that the presence of a process results in an estimated log removal of pathogens, sometimes taking into account operational conditions. As the risk posed by a supply is likely to be influenced to a significant degree by the operational performance in managing the supply, such approaches should not be solely relied upon for individual supplies.

It is recommended that when undertaking a risk assessment of a water supply, it should be based on the assessment of the water quality data obtained from monitoring or assessment programmes, with data being available throughout the system. For microbial risks, it is preferable that such assessments would draw, at least in part, on pathogen analysis but it is recognised that in many cases risk assessments may have to be performed using data on indicator and index organisms (Haas et al., 1999). This approach was adopted in Kampala and the case studies outlined provide an indication of how risk assessments may be performed.

Case study examples from Kampala

Risk assessments of the piped water supply were undertaken for *E.coli O157:H7*, *Cryptosporidium parvum* and rotavirus. The assessment for *E.coli O157:H7* is based primarily on data obtained for thermotolerant coliforms from monitoring programmes. The assessment for *Cryptosporidium parvum* is based on removal of *Clostridium perfringens* spores. The assessment for rotavirus is based removal of coliphage. The justification for each assessment is provided in the specific case studies.

In all the risk assessments, the susceptible fraction is based on known rates of access to piped water supply in Kampala using a direct household connection rate of 20% of the population and an estimated 70% of the unserved population using taps (Howard et al., 2002). Using data from water usage studies the following patterns of use are determined.

- 25.2% of the unserved population only use a single tap source.
- 3.6% of the unserved population use 2 tap sources and no other form of supply.
- 30.8% of the unserved population use a tap as a first source and another form of supply as a second source.
- 8.2% of the unserved population use a tap as a second source and other form of supply for the first source.

One of the major issues facing the application of risk assessment models in developing countries is how to assess exposure among the population that commonly use more than one type of drinking-water source. It should be noted that in this case, only exposure from drinking-water is considered and not the broader allocation of exposure between different routes, such as poor hygiene and food. The population using multiple sources are in principle exposed from two different sources, and in allocating a risk from an individual source, the potential for the alternative source to be the route of exposure must be taken into account. There are two ways in which this could be addressed:

1. All exposure could be allocated to each source. This may be legitimate in that the potential for exposure exists from both sources, but in reality may significantly over-state the allocation of exposure to one source if this is of significantly higher quality.

2. Exposure could be allocated between the sources with a 'discounting' factor for exposure allocated to each source. This has an advantage in that it may reflect reality more reliably, but represents difficulties in determining what form of 'discounting' is employed.

In this case study, we have opted for the second approach and used a 'discounting' factor based on the estimated proportional uses of water from multiple sources. This assumes that exposure is solely a function of the proportion of water estimated to be collected from each source, rather than contaminant loads within each source and is based on the assumption that all sources of water have the potential to be a route of exposure. In allocating a discounting factor, the limited data on proportional use in Kampala resulted in a gross assumption that two-thirds of all water collected should be allocated to the first source and one-third to the second source. On the basis of data collected through water usage studies in Kampala (Howard et al., 2002), this was considered a reasonable assumption.

In the case study, therefore, where taps were the first source, the percentage of unserved population using the tap is multiplied by 0.67 to allocate a third of exposure to the alternative source. Where taps were the second source, the figure is multiplied by 0.33 to allocate two-thirds of the exposure to other sources. No account was made for exposure resulting from re-contamination during transport and storage. This is dealt with in a separate risk assessment exercise.

A final figure was obtained by converting the total percentage of the unserved population calculated as being exposed into a percentage of the overall population by multiplying by 0.8 (as 80% of the total population fell into this group) and adding this to the 20% receiving water through yard or higher level of service.

This gives a total percentage of the unserved population susceptible as being:

Percent population using other water sources exposed from piped water =
(30.8 x 0.67) + (8.2 x 0.33) = 23.3%

- Total percent of unserved population exposed = (25.2+3.6+23.3) = 52.1%

- Total percent of unserved population exposed as proportion of total population = (52.3 x 0.8) = 41.8%

Total population exposed = 20% + 41.8% = 61.8%

For the risk assessment this was rounded up to 62% for ease of calculation. There are two treatment works (Gaba 1 and Gaba 2) that serve Kampala. For this first assessment it is assumed that each serve an equal number of people and allocated 31% of the total population, although it is likely that there is a difference in the number of people using water from the two treatment works.

A further reduction for the susceptible fraction is allowed for the risk assessment of *E.coli O157:H7* in the distribution system, this takes into account the location of contamination events, as described below. It is assumed that all the population exposed will be susceptible to infection to *E.coli O157:H7* and *Cryptosporidium parvum*. Although some immunity to these pathogens may have been acquired, it is assumed here that this is relatively short-lived. For rotavirus, this figure is further reduced to take into account the specific vulnerability of young children, and the development of adult immunity, and 17% of the total population calculated above is considered susceptible based on WHO (2003).

E.coli O157:H7

This assessment was based on several sets of data, including a specific assessment of the treatment works for the Kampala system, annual water quality data from the two treatment works and data from the distribution system derived from a surveillance project in 1997 and 1998.

The risk from water in the distribution system is an annualised risk, based on average contamination, as indicated by thermotolerant coliform concentrations. It is assumed that 95% of these are *E.coli* (WHO, 1993) and that 8% of all *E.coli* are pathogenic (Haas et al., 1999). The average from the surveillance data is therefore multiplied by 0.95 and then by 0.08. This can be summarised as follows:

E.coli = No. thermotolerant coliforms x 0.95

E.coli O157:H7 = *E.coli* x 0.08

The figures in the risk assessment are expressed in organisms per litre, and therefore, this figure is multiplied by 10 in order to gain a final figure. The dose-response is based on *Shigella*, which it is estimated has a 1.0×10^{-3} risk of infection from exposure to a single organism (Rose and Gerba, 1991; Haas et al., 1999). The risk of developing illness once infected is more problematic as there is limited consolidated data available. At present the proportion is set at 25%, based on the morbidity ratio for *Shigella* (Haas et al., 1999). There remains a lack of reliable data for *E.coli O157:H7*. For instance, the best-documented recent outbreak was in Walkerton, Ontario, but it appears difficult to differentiate the numbers of people actually infected by *Campylobacter jejeuni* and those infected by *E.coli O157:H7*.

The treatment effect is calculated based on two assumptions. Firstly, the raw water at Gaba 1 had one result of 16cfu/100ml or 160cfu/litre. As there were no organisms in the final water, this indicates that the log reduction must have been at least between 10^2 and 10^3. Two additional log reduction credits were given to take account of disinfection performance, as free chlorine levels were consistently over 0.2mg/l after 30 minutes contact time. This gives a final log reduction of 10^5. It was considered likely that the absence of organisms in the final water reflected actual removal at the higher level.

The risk assessment on the distribution system removes the first two terms of raw water quality and treatment effect, and starts with the drinking-water quality, which is the average contamination based on 713 analyses of thermotolerant coliforms in 1998 and 913 in 1999. The susceptible fraction is reduced for the distribution assessment to 0.1 as all the failures occurred at end of lines. Although the risk assessment is for the whole system, it is considered unrealistic to set the susceptible fraction as high as for the treatment works.

The assessment data suggests a final risk at a disease burden of 1.45E-05 for Gaba 1 and 4.34E-06 for Gaba 2, with a likelihood of diarrhoea of 1.46E-04 and 4.38E-05 respectively. The risk estimates expressed as a disease burden slightly exceed the WHO Guidelines reference level of risk of 10E-06. Taking the average level of contamination from these supplies the levels of risk are even lower (1.36E-07 for Gaba 1 and 1.45E-07 for Gaba 2) indicating that these meet current WHO Guidelines for health-based targets. Taking the average contamination in distribution, the risks are much higher (5.26E-04 for 1998 and 2.92E-04 for 1999), suggesting that post-works contamination represents a much greater problem than treatment failure.

Cryptosporidium parvum

This assessment was based on a specific assessment of the treatment works for the Kampala system in 2002 for *Clostridium perfringens*. The risk assessment uses the

Table 2.8. Risk assessment for *E.coli O157:H7* at treatment works using assessment data, 2002

	Calculated terms	Gaba 1	Gaba 2
Raw water quality (C_R)		160	48
Treatment effect (PT)		0.99999	0.99999
Drinking-water quality (C_D)	C_R x (1-PT)	1.60E-03	4.80E-04
Consumption of unheated drinking-water (V)		1	1
Exposure by drinking-water, organisms per litre (E)	C_D x V	1.60E-03	4.80E-04
Dose-response (r)		1.00E-3	1.00E-3
Risk of infection per day ($P_{inf,d}$)	E x r	1.60E-06	4.80E-07
Risk of infection per years ($P_{inf,y}$)	$P_{inf,d}$ x 365	5.84E-04	1.75E-04
Risk of diarrhoeal disease given infection ($P_{ill\|inf}$)		0.25	0.25
Risk of diarrhoeal disease (P_{ill})	$P_{inf,y}$ x $P_{ill\|inf}$	1.46E-04	4.38E-05
Disease burden (db)		3.20E-01	3.20E-01
Susceptible fraction (fs)		0.31	0.31
Disease burden (DB)	Pill x db x fs	1.45E-05	4.34E-06

Table 2.9. Annualised risk assessment for *E.coli O157:H7* at treatment works using monitoring data, 1999

	Calculated terms	Gaba 1	Gaba 2
Average raw water quality (C_R)		15	16
Treatment effect (PT)		0.99999	0.99999
Drinking-water quality (C_D)	C_R x (1-PT)	1.50E-05	1.60E-05
Consumption of unheated drinking-water (V)		1	1
Exposure by drinking-water, organisms per litre (E)	C_D x V	1.50E-05	1.60E-05
Dose-response (r)		1.00E-3	1.00E-3
Risk of infection per day ($P_{inf,d}$)	E x r	1.50E-08	1.60E-08
Risk of infection per years ($P_{inf,y}$)	$P_{inf,d}$ x 365	5.84E-06	5.84E-06
Risk of diarrhoeal disease given infection ($P_{ill\|inf}$)		0.25	0.25
Risk of diarrhoeal disease (P_{ill})	$P_{inf,y}$ x $P_{ill\|inf}$	1.37E-06	1.46E-06
Disease burden (db)		3.20E-01	3.20E-01
Susceptible fraction (fs)		0.31	0.31
Disease burden (DB)	P_{ill} x db x fs	1.36E-07	1.45E-07

Table 2.10. Annualised risk assessment for *E.coli O157:H7* using annual data in distribution system

	Calculated terms	1998	1999
Drinking-water quality (C_D)		0.18	0.10
Consumption of unheated drinking-water (V)		1	1
Exposure by drinking-water, organisms per litre (E)	C_D x V	1.80E-01	1.00E-01
Dose-response (r)		1.00E-3	1.00E-3
Risk of infection per day ($P_{inf,d}$)	E x r	1.50E-05	1.60E-05
Risk of infection per years ($P_{inf,y}$)	$P_{inf,d}$ x 365	1.00E-3	1.00E-3
Risk of diarrhoeal disease given infection ($P_{ill\|inf}$)		0.25	0.25
Risk of diarrhoeal disease (P_{ill})	$P_{inf,y}$ x $P_{ill\|inf}$	1.64E-02	9.13E-03
Disease burden (db)		3.20E-01	3.20E-01
Susceptible fraction (fs)		0.1	0.1
Disease burden (DB)	P_{ill} x db x fs	5.26E-04	2.92E-04

data for *Clostridium perfringens* as an index for the removal of *Cryptosporidium parvum*. Therefore, all data relates directly to *Clostridium perfringens* but is taken to reflect the movement of *Cryptosporidium*. The risk assessment must be considered only very provisional as there is no data on source water concentrations of *Cryptosporidium parvum*, which would have a significant impact on the final risk estimate.

Table 2.11. Risk assessment for *Cryptosporidium parvum* using *Clostridium perfringens* data

	Calculated terms	Gaba 1	Gaba 2 (normal)	Gaba 2 (failure)
Raw water quality (C_R)		2000	20	210
Treatment effect (PT)		0.9999	0.9999	0
Drinking-water quality (C_D)	C_R x (1-PT)	2.00E-01	5.00E-03	2.10E+2
Consumption of unheated drinking-water (V)		1	1	1
Exposure by drinking-water, organisms per litre (E)	C_D x V	2.00E-01	5.00E-03	2.10E+2
Dose-response (r)		4.00E-03	4.00E-03	4.00E-03
Risk of infection per day ($P_{inf,d}$)	E x r	8.00E-04	2.00E-05	8.40E-01
Risk of infection per years ($P_{inf,y}$)	$P_{inf,d}$ x 365	2.92E-01	7.30E-03	3.07E+02
Risk of diarrhoeal disease given infection ($P_{ill\|inf}$)		0.30	0.30	0.30
Risk of diarrhoeal disease (P_{ill})	$P_{inf,y}$ x $P_{ill\|inf}$	8.76E-02	2.19E-03	9.20E+01
Disease burden (db)		1.50E-01	1.50E-01	1.50E-01
Susceptible fraction (fs)		0.31	0.31	0.31
Disease burden (DB)	P_{ill} x db x fs	4.07E-03	1.02E-04	4.28E+00

The treatment effect is difficult to quantify. Using the data from *Clostridium perfringens*, it is clear that at least 10^4 removal was achieved in Gaba 1. From the assessment a similar figure is allocated to Gaba 2, although raw water concentrations were lower. There was one failure at Gaba 2 and this is presented separately to demonstrate how the risk increased during the period of failure. The dose-response point estimate is taken from WHO (2003). The risk of developing illness is based on the review by Havelaar and Melse (2003).

There is a present risk of an exposed individual having 8.76E-02 cases of diarrhoea per year. This seems to represent a relatively high risk and in part reflects the limited data available, but also the high mortality burden among people who are HIV positive or have AIDS associated with this pathogen. This level of risk from the water supply appears reasonably compatible with the reported rates of *Cryptosporidium* in the literature and because the treatment works was not designed to take into account *Cryptosporidium* removal.

Rotavirus

This assessment was based on an assessment of the treatment works for the Kampala system in 2003 for coliphage. The risk assessment uses the data for

Table 2.12. Risk assessment for rotavirus using coliphage data

	Calculated terms	Gaba 1	Gaba 2
Raw water quality (C_R)		1000	0.9
Treatment effect (PT)		0.9999	0.9999
Drinking-water quality (C_D)	C_R x (1-PT)	1.00E-01	9.00E-05
Consumption of unheated drinking-water (V)		1	1
Exposure by drinking-water, organisms per litre (E)	C_D x V	1.00E-1	9.00E-05
Dose-response (r)		2.70E-01	2.70E-01
Risk of infection per day ($P_{inf,d}$)	E x r	2.70E-02	2.43E-05
Risk of infection per years ($P_{inf,y}$)	$P_{inf,d}$ x 365	9.85E+00	8.87E-03
Risk of diarrhoeal disease given infection ($P_{ill\|inf}$)		0.50	0.50
Risk of diarrhoeal disease (P_{ill})	$P_{inf,y}$ x $P_{ill\|inf}$	4.93E+00	4.43E-03
Disease burden (db)		3.20E-01	3.20E-01
Susceptible fraction (fs)		0.05	0.05
Disease burden (DB)	P_{ill} x db x fs	7.88E-02	7.10E-05

coliphage as an index for the removal of rotavirus which is taken to reflect the movement of rotavirus. The risk assessment must be considered provisional, as there is no data on source water concentrations of rotavirus, which would have a significant impact on the final risk estimate.

The raw water estimate for Gaba 1 is the average of samples taken on three consecutive days multiplied by 1000 to give a concentration per litre. The estimate for Gaba 2 is based on a lack of isolation of organisms and therefore set below detection in a one litre sample. The treatment effect is difficult to quantify. Using the data from coliphage, it is clear that around 10^4 removal can be attributed to Gaba 1. From the assessment, a similar figure is allocated to Gaba 2, although raw water concentrations were lower. The dose-response point estimate is taken from WHO (2003). The risk of developing illness is based on the review by Havelaar and Melse (2003). The susceptible fraction for each works is based upon 17% of the population of the 31% allocated to each works being susceptible. Table 2.12 summarises the simplified risk assessment.

The final burden of disease associated with rotavirus from the risk assessment is high for Gaba 1 at 7.88E-02. For Gaba 2, the risks are much lower, with a final disease burden of 7.10E-05 and a likelihood of 4.43E-03 of an episode of diarrhoea.

The figures for Gaba 1 probably overstate the risk from rotavirus in the water supply and is largely because the treatment effect is relatively limited at 4 logs. The lack of isolation of phage plaques in the final water makes more reliable estimates difficult. Although the risk does appear to be over-estimated, it is likely that water does provide a significant proportion of rotaviral infections and as noted above, this pathogen is associated with a high incidence in developing countries. For Gaba 2, the estimates may be slightly underestimated, although with both coagulation-flocculation-settling and disinfection it would be expected that most viruses would be successfully removed.

Discussion of case study findings

There are clear limitations to this risk assessment. For *E.coli O157:H7*, the estimates are based on presumed proportions of generic *E.coli* that are pathogenic. This may significantly over-estimate the risk. If the proportion of *E.coli* considered likely to be O157:H7 was reduced by an order of magnitude, so would the final risk estimates. However, using 8% is still considered reasonable, as although this may not represent directly *E.coli O157:H7*, it would provide a reasonable estimate of the overall health burden derived from bacterial pathogens.

The risk assessment for *Cryptosporidium parvum* is more problematic as there is no obvious direct relationship with numbers of *Clostridium perfringens* in source waters, although the removal rates would be indicative of *Cryptosporidium* removal. However, WHO (2003) provide a review of moderate to high concentrations of *Cryptosporidium parvum* in raw water and indicate that this ranges between 30 and 300. Therefore the model used may not be too unrealistic. It is of greater concern that only a small number of samples are available from a single assessment. The collection of further data is planned and should lead to improvements in the risk assessment.

The risk assessment for rotavirus probably significantly over-estimates the disease burden associated with this pathogen for Gaba1 and may underestimate the risk from Gaba 2. Further data are required to develop this risk assessment, and in particular, to attempt to see what level of coliphage in the raw water at Gaba 2 actually exists. Again the limited data set is of concern.

WHO have suggested that a reasonable reference level of risk from pathogens in water is 10E-06 risk of infection. If the Kampala data are compared against this, a number of key findings emerge. For *E.coli O157:H7*, there appears to be relatively little risk from water leaving the treatment works. The assessments performed in 2002 suggest that the risk exceeds the WHO reference level, although this is only marginally higher and when considering other routes of transmission and the risk posed by the common alternative sources, the risk is very low. This suggests that for bacterial pathogens, there is no need for improvement at the treatment works.

The risk is significantly increased within the distribution system and this indicates that this is where the primary risk from the piped water system is found. This indicates that the area where investment is required in operation, maintenance and upgrading is the distribution system. Tackling issues such as leakage control is likely to be essential in this process. This finding is expected. Water quality problems are more typically associated with poor distribution systems than failures in treatment works in developing countries, and have led to outbreaks in developed countries (Clark et al., 1993; Geldreich, 1996).

The *Cryptosporidium* risks are relatively high, although as noted above these results are only very provisional. Gaba 1 under normal conditions retains a high risk simply because the treatment processes applied provide limited security for *Cryptosporidium parvum* removal. It is interesting to note that under normal conditions that Gaba 2 would represent a much lower risk than Gaba 1, but failure was only noted in this works. It remains some what difficult to state definitively what the level of risk from *Cryptosporidium* in the water supply represents, particularly in comparison to other transmission routes. This is an area where a review of available data or undertaking a prevalence study would be of use.

It is not unrealistic, however, that a high level of risk will be posed by *Cryptosporidium*. Within Kampala, transmission direct from animals may occur, but is unlikely to be widespread. The water supply would not have been designed with *Cryptosporidium* removal in mind and therefore would not necessarily be capable of removing this to a satisfactory degree. It would seem that investment in treatment works would be of benefit for *Cryptosporidium* removal, although this would be best achieved through improving the coagulation-flocculation-settling and rapid sand filtration given that improvements in operational performance should deliver significant improvements in removal. The provision of ozonation, as an alternative approach would be likely to be prohibitively expensive.

Using risk assessment data for investment planning

The previous case studies have provided an indication of the risk associated with the supply under current conditions. If a performance target were to be set using the WHO reference level of risk at 10^{-6}, the same matrix can be used to define the expected reduction through the treatment works by changing the final disease burden (DB) term in the methodology outlined in Table 2.7, to 10^{-6}, whilst retaining the same raw water quality dose response and disease burden per case.

For *E.coli* this would require an improvement to approximately 6 logs, 7 logs for *Cryptosporidium* and up to 8 logs for rotavirus in Gaba 1, but only 5 logs in Gaba 2.

Whilst it is potentially feasible to reach such levels of performance, it is questionable whether this would be cost-effective, given the low levels of access to piped water in the home, use of alternative (and more contaminated) water sources and low sanitation coverage. Improving access to water supply, improvement in hygiene and increased access to sanitation would be likely to deliver much greater health gains. Once these goals had been achieved, the disease burden per case from the pathogens may have decreased, as improvements in nutrition and boosting of immune systems may reduced the number of individuals developing more severe end-points. Furthermore, ongoing efforts to reduce HIV prevalence would also be expected to significantly reduce the mortality burden. Therefore, the actual level of investment required to meet the WHO reference level of risk in the future may be significantly lower than at the present time, with a greater likelihood of reducing disease burdens.

In overall terms, the risk posed by the piped water supply is relatively low, and for bacterial pathogens leaving the treatment works, is generally consistent with the WHO reference level of risk. The reference risk is exceeded quite considerably in the distribution network and there is a need for investment to improve operation and maintenance in the distribution systems. The reference level of risk from *Cryptosporidium* is exceeded by a much greater extent in water leaving the treatment works and would warrant some investment in improving the treatment works. The scale of investment should, however, be balanced against the need to increase access to high service levels. As a means of comparing the risk associated with re-contamination of household water and the use of protected springs in Kampala, risk assessments for *E.coli O157:H7* were performed using data generated between 1997 and 1999 in a surveillance project.

A risk assessment for *E.coli O157:H7* was performed on household water where sources could be matched to household water. These were not all taken from Kampala, but from other supplies operated by NWSC. A total 97 samples were included within the risk assessment. A median concentration of 3 cfu/100ml was obtained, which was calculated to be equivalent to 2.3 *E.coli 0157:H7* per litre. As this comparison was only valid for the population using communal sources of piped water, the susceptible fraction was adjusted to 42% to maintain an estimate of the fraction of risk from water supply in the population that results from re-contamination. A final disease burden of 2.82E-02 was obtained with a likelihood of 2.10E-01 cases of diarrhoea per person per year resulting. The risk assessment of the water in the distribution system itself was adjusted to a similar susceptible population fraction and the data for 1999 used. This gave a final disease burden of 1.23E-03, with a likelihood of 9.13E-03 cases of diarrhoea per person per year.

The data on re-contamination of household water indicates that the disease burden estimates from re-contamination was over one order of magnitude higher than that posed directly from the piped water itself, and the likelihood of diarrhoea two orders of magnitude higher. It should also be noted that the use of NWSC water was found to be associated with better quality of household water than other sources of water. This assessment should be treated with some caution as the two data sets are of different size and much of the household water data are drawn from other towns, although there was no significant difference in average quality from that of Kampala. It does, however, point to the need for improved water hygiene over improvement in quality in supply for the population without their own connection, even when only assessing in relation to risk posed by re-contaminated water. These risks could, of course, be greatly reduced by using household water treatment as a further 4-5 log reduction from using chlorine-based treatment (Sobsey, 2002). This would lead to a final disease burden estimate of 1.23E-08 level of risk and a likelihood of 9.12E-08 cases of diarrhoea per person per year. Given that diarrhoea reductions for handwashing and household water treatment are of a similar order of magnitude (Sobsey et al., 2003) a further level of reduction in risk could be achieved through handwashing interventions.

The risk assessment for springs was based on a longitudinal study of 63 springs in high, medium and low density areas of Kampala, with a total of 609 samples taken between April 1998 and March 1999. The springs varied in their condition, with high-density areas being generally less well maintained and having higher sanitary risk scores (Howard et al., 2003). An annualised disease burden for a susceptible fraction of 28% of the population using springs (100% minus the proportion allocated to piped water) was calculated at 8.67E-02 DALYs, with a total of 3.20E-01 cases of diarrhoea per person per year. The disease burden is over one order of magnitude higher than the risk posed by the piped water supply, and for cases of diarrhoea, exceeds the risk from piped water by about 1.5 orders of magnitude. This is supported by other findings that showed the use of non-piped water sources was a significant risk factor for severe childhood diarrhoea in Uganda (Nasinyama et al., 2001).

The water in springs also exceeds the risk associated with re-contamination of NWSC water, and the likelihood of diarrhoea was roughly the same as the likelihood associated with re-contamination of household water. This assessment further emphasises the value in improving access to the current NWSC supply as a means of reducing health risks.

In terms of the risk assessment process, it would appear that the simplified methodology used in Uganda appears to work and provide outcomes that can be considered realistic in terms of the literature surrounding diarrhoeal disease incidence. The use of point risk estimates is perhaps the greatest weakness, and as noted by WHO (2003) and Haevlaar and Melse (2003), full risk assessments should take into account variability and uncertainty through the use of statistical distributions. The use of the simplified methodology does at least provide a first estimate of the health burden from microbial contaminants, which can be improved over time once data becomes more available.

A second area where there is significant uncertainty is the use of 'discounting' factors to take into account multiple source use and allocation of reasonable proportion of total exposure to an individual source. Although this is likely to be somewhat controversial, the use of total use as a means of allocating exposure does at least attempt to reflect the reality of water collection patterns and, therefore, potential exposure. This is an area where further work and research is likely to be required.

Conclusions

Quantified microbial risk assessment appears to be feasible for developing countries; although these still rely on indicator organism data and several assumptions must be made. Although the final estimates for the piped water in Uganda are subject to significant uncertainty, these still appear realistic, and would aid investment planning and decision-making for promoting safer water supply. Further data are required to refine these estimates, or at least to try and assess the degree to which this current risk assessment deviates from estimates based on pathogen data.

Within the Uganda setting, three key findings emerge of particular interest to policy makers and water safety managers.

1) Water quality deterioration in the distribution system represents a far greater risk than treatment performance. This finding is similar to others from the developed and developing world. This implies that the main need for water safety improvement in Kampala is within distribution management rather than treatment plant upgrades.

2) For bacterial pathogens, the alternative supplies (protected springs) and re-contamination of water pose a greater risk to health than the water in the piped

distribution system. This suggests that increasing access to piped water closer to people's homes and promotion of household treatment of water is important to promote better health. However, this should be balanced with the need to ensure better water safety management within the distribution system: as increasing numbers of users will result in a changing risk assessment result.

3) At the water treatment works, the risks posed by *Cryptosporidium* are significantly higher than those for other pathogens. This is not unexpected as the works were not designed with *Cryptosporidium* removal in mind. There is great reliance on chlorination to produce safe water, which whilst effective against bacterial and (to a lesser extent) viral pathogens, will be ineffective for protozoa. Any upgrading for water quality improvements should therefore be based on improvement of *Cryptosporidium* removal, primarily through the use of coagulation-flocculation-settling, to improve removal efficiency in rapid sand filtration. Further work is also required to assess the level of *Cryptosporidium* in the source waters.

References

Bhimma, B., Rollins, N., C., Coovadia, H., M., and Adhikari M., (1997) Post-Dysenteric Hemolitic Uremic Syndrome in Children during an Epidemic of *Shigella* Dysentry in Kwa-Zule/Natal, *Pediatric Nephrolog*, 11, pp. 560-564.

Birmingham M., E., Lee, L., A., Ntakibirora, M., Bizimana, F., Deming, M., S., (1997) A Household Survey of Dysentery in Burundi: Implications for the Current Pandemic in Sub-Saharan Africa, *Bulletin of the World Health Organization* 75(1), pp. 45-53.

Clark, R., M., Goodrich, J., A., and Wymer, L., J., (1993) Effect of the Distribution System on Drinking-Water Quality, Journal of Water Supply Research and Technology, *Aqua* 42, pp.30-38.

Cunin, P., Tedjouka, E., Germani, Y., Ncharre, C., Bercio, R., Morvan, J. and Martin, P., M., (1999) *Escherichia coli O157* Emerging in Cameroon? *Emerging Infectious Diseases*, 5, pp. 285-290.

Geldreich, E., E., (1996) *Microbiol Quality of Water Supply in Distribution Systems*. Lewis Publishers, New York.

Haas, C., N., Rose, J., B. and Gerba, C., P., (2000) Development of a Dose-Response Relationship for *Escherichia coli O157:H7, International Journal of Food Microbiology*, 1748, pp. 153-159.

Harries, A., (1991) Some Clinical Aspects of HIV Infection, Current Opinion in Infectious Diseases, 14(15), pp. 567-571.

Havelaar, A., H., Hollander de A., E., M., Teunis, P., F., M., Evers, E., G., Kranen van H., J., Versteegh, F., M., Koten van J., E., M., and Slob, W., (1996) Balancing the Risks and Benefits of Drinking-Water Disinfection: Disability-Adjusted Life Years on the Scale, *Environmental Health Perspective*, 108, pp. 315-321.

Havelaar, A., H. and Melse, J., M., (2003) *Quantifying Public Health Risks in the WHO Guidelines for Drinking-Water Quality: A Burden of Disease Approach*, Report 734301022/2003, RVIM, Bilthoven, Netherlands.

Hellard, M., E., Sinclair, M., I., Forbes, A., B., Fairley, C., K., (2001) A Randomized, Blinded, Controlled Trial Investigating the Gastrointestinal Health Effects of Drinking-Water Quality, *Environmenal Health Perspectives*, 109(8), pp. 773-778

Howard, G., Teuton, J., Luyima, P., Odongo, R., (2002) Water Usage Patterns in Low-Income Urban Communities in Uganda: Implications for Surveillance, *International Journal of Environmental Health Research*, 12(1), pp. 63-73.

Howard, G., Bartram, J., (2003) *Domestic Water Quantity, Service Level and Health*, WHO, Geneva.

Howard, G., Pedley, S., Barrett, M., Nalubega, M., and Johal, K., (2003) Risk Factors Contributing to Microbiological Contamination of Shallow Groundwater in Kampala, Uganda, *Water Research*, 37, pp. 3421-3429.

Hunter, P., R., (2003) Drinking-water and Diarrhoeal Disease due to *Escherichia coli*, *Journal of Water and Health*, 1(2), pp. 65-72.

Hunter, P., R., and Syed, Q., (2001) Community Surveys of Self-Reported Diarrhoea can Dramatically Overestimate the Size of Outbreaks of Waterborne Cryptosporidiosis, *Water Science and Technology*, 43(12), pp. 27-30.

Kelley, P., Sri Baboo, K., Ndubani, P., Nchito, M., Okeowo, N., P., Luo., N., P., Feldman, R., Farthing, M., J., G., (1997) Cryptosporidiosis in Adults in Lusaka, Zambia and its Relationship to Oocyst Contamination of Drinking-water, *Journal of Infectious Diseases*, 176(4), pp. 1120-1123.

Kotloff, K., L., Winickof, J., P., Ivanoff, B., Clemens, J., D., Swerdlow, D., L., Sansonetti, P., J., Adak, G., K. and Levine, M., M., (1999) Global Burden of

Shigella Infections: Implications of for Vaccine Development and Implementation of Control Strategies, *Bulletin of the World Health Organization*, 77(8), pp.651-666.

Mackenzie, W., R., Hoxie, N., J., Proctor, M., E., Gradus, M., S., Blair, K., A., Peterson, D., E., Kazmierczak, J., J., Addiss, D., G., Fox, K., R., Rose, J., B., Davis, J., P., (1994) A Massive Outbreak in Milwaukee of Cryptosporidium Infection Transmitted through the Public Water Supply, *New England Journal of Medicine*, 331, pp. 161-167.

Murry, C., J., L., Lopez, A., D., (1996) *The global burden of disease,* World Health Organization, Geneva.

Nasinyama, G., W., McEwen, S., A., Wilson, J., B., Waltner-Towers, D., Gyles, C., L., Opuda-Asibo, J., (2000) Risk Factors for Acute Diarrhoea among Inhabitants of Kampala District, Uganda, *South African Medical Journal*, 90(9), pp. 891-898.

Mwachari, C., Batchelor, B., I., Paul., J., Waiyaki, P., G. and Gilks, C., F., (1998) Chronic Diarrhoea among HIV-Infected Adult Patients in Nairobi, Kenya, *Journal of Infection*, 37(1), pp. 48-63.

Mølbak, K., Anderson, M., Aaby, P., Højlyng, N., Jakobsen, M., Sodemann, M. and da Silva, A., P., (1997) Cryptospordium Infection in Infancy as a Cause of Malnutrition: A Community Study from Guinea-Bissau, West Africa, American *Journal of Clinical Nutrition*, 65(91), 149-152.

Payment, P., Richardson, L., Siemiatycki, J., Dewar, R., Edwardes, M., Franco, E., (1991) A Randomised Trial to Evaluate the Risk of Gastrointestinal disease due to Consumption of Drinking-Water meeting Current Microbiological Standards, *American Journal of Public Health*, 81(6), pp. 703-708.

Prüss, A., Kay, D., Fewtrell, L. and Bartram, J., (2002) Estimating the Burden of Disease from Water, Sanitation and Hygiene at a Global Level, *Environmental Health Perspectives*, 110(5), pp. 537-542.

Regli, S., Rose, J., B., Haas, C., N., Gerba, C., P., (1991) Modelling the Risk from Giardia and Viruses in Drinking-Water, *Journal of the American Water Works Association*, 83(11), pp. 76-84.

Sobsey, M. (2002) *Managing Water in the Home: Accelerated Health Gains from Improved Water Supply*, World Health Organization, Geneva.

Sobsey, M., D., Handzel, T. and Venczel, L. (2003) Chlorination and Safe Storage of Household Drinking-Water in Developing Countries to Reduce Waterborne Disease, *Water Science and Technology*, 47(3), pp. 221-228.

Sodemann, M., Jakobsen, M., S., Mølbak, K., Martins, C. and Aaby, P., (1999) Episode-Specific Risk Factors for Progression of Acute Diarrhoea to Persistent Diarrhoea in West African Children, Transactions of the Royal Society of Tropical Medicine and Hygiene, 93(1), pp. 65-68.

Strachan, N., J., C., Fenlon, D., R. and Ogden, I., D., (2000) Modelling the Infection Pathway and Infection in an Environmental Outbreak of *Escherichia coli O157*, *FEMS Microbiology Letters*, 2003, pp. 69-73.

Tarimo, D., S., Killewo, J., Z., Mingas, J., N. and Msamanga, G., I. (1996) Prevalence of Intestinal Parasites in Adult Patients with Enteropathic AIDs in North-Eastern Tanzania, *East African Medical Journal*, 73(6), pp. 397-399.

UNAIDS (2003), www.unaids.org

WHO (1996) *Guidelines for Drinking-Water Quality: Volume 2 Health and other Supporting Criteria 2nd Edition*, World Health Organization, Geneva.

WHO (2002) *World Health Report: Reducing Risks and Promoting Healthy Life*, World Health Organization, Geneva.

WHO (2004) *Guidelines for Drinking-Water Quality: Volume 1 Recommendations 3rd Edition*, World Health Organization, Geneva.

Westrell, T., Bergstedt, O., Stenström, T., A. and Ashbolt, N., J. (2003) A Theoretical Approach to Assess Microbial Risks due to Failures in Drinking-Water Systems, *International Journal of Environmental Health Research*, 13(2), pp. 181-197.

Chapter 3

Institutional aspects

by Sam Godfrey, Dr Sam Kayaga, Dr Guy Howard & Kevin Sansom

Introduction

Risk assessment and management of piped urban systems requires the involvement of various stakeholders. For example, to assess the risk of a piped water supply to a leaking sewer necessitates participation from the operators of the water supply and sewer network, as well as, the water quality analysts. Understanding the roles, responsibilities and interdepartmental relationships that exist in risk assessment and management requires detailed allocation of institutional roles and responsibilities. Therefore, without a clear understanding of the current and expected roles under the risk assessment and management framework, it is difficult to assign responsibilities to each stakeholder. This chapter outlines methods that may be used to incorporate institutional analysis into WSPs. It is divided into two clear sections; the first section presents institutional analysis tools required during the risk assessment of piped urban water supplies. The second section discusses examples of specific activities and responsibilities each department may have in risk management.

Institutional analysis for risk assessment

Who's involved?

During the preparation of a WSP it is critical to undertake a risk assessment of the water supply to establish which points pose the greatest public health risk. This can only be achieved if led by an interdepartmental team. Therefore, the first step to achieving a WSP is to understand the institutional framework in which the water supply is currently being operated (i.e., who is involved). It is not only important to explore the institutional landscape in which the WSP is operational; it is also paramount to understand the organisational set-up of each of the stakeholders: it is important to know who owns and operates the water treatment and distribution systems, how they are operated, as well as, who is responsible for the quality control aspects. Analysis of the level of private sector involvement in the provision of water services would be a good starting point for assessment to begin. Table 3.1 gives a model of options for management of urban water supplies in the private sector. The model provides several combinations of ownership and asset operation. The analysis of these management models provides basic information on the operation and management of a water supply.

Another tool commonly used for more detailed institutional analysis is the Stakeholder Analysis. This may be accomplished by drawing up a list of all the key stakeholders involved in the management of the piped water supply that is the subject of the study. In many cases, this will involve more than one stakeholder. For example, one department may be responsible for quality control and another for investment planning. Therefore, it is important to analyse the relationship (declared and undeclared) that exists between the different stakeholders. During this research, an institutional analysis was undertaken in Guntur, India and Kampala, Uganda (see Box 3.1 and 3.2 for details).

As well as the internal environment, consideration should be given to external stakeholders. These include stakeholders responsible for monitoring or regulating the performance of the bulk provider or operational groups. The regulatory body (if one exists) may be an Environmental Health Unit of the Ministry of Health or

Table 3.1. A management model of urban water supply organisations

Organisational type	Who owns the infrastructure?	Who operates infrastructure?	Legal status of operator	Who owns the shares?
Direct public/local	Local (municipal government)	Municipal administration	Municipal department	Not applicable
Direct public/supra-local	National or state government	National or state government administration	National or state government department	Non applicable
Corporatized utility (corporate/authority board)	Government or utility	Corporatized utility	Parastatal usually defined by special law	Not applicable
Government owned public limited company (plc)	Government of PLC	PLC as permanent concessionaire	Public limited company	Local/provincial government
Delegated private	Any combination of government agencies	Government and temporary concessionaire	Public limited company	Private stakeholders
Direct private	Private agents	Private company	Public limited company	Private stakeholders

Source: (DFID 1998)

Box 3.1. Institutional arrangement – Guntur, AP, India

Guntur is a municipal town within the Indian state of Andrapradesh. An initial listing of the stakeholders involved in water supply in Guntur reveals a direct public management model between the state capital of Hydrabad and the municipality of Guntur. In total, three stakeholders are involved: including the Institute of Preventive Medicine, the Directorate of Municipal Administration and the AndraPradesh State Pollution Board (Chary et al., 2003).

Box 3.2. Institutional arrangement – Kampala, Uganda

In Kampala, up to January 2004, the system was operated under a public-private management model. There was a strong inter-linkage between departments. Activity responsibility matrices drawn in the year 2002 showed that the operation of the water treatment works was the responsibility of the government parastatal National Water and Sewerage (NWSC), and the operation of the distribution piped network was the responsibility of Ondeo Services Uganda Ltd (OSUL) (Godfrey et al., 2002).

Potable Drinking-Water Quality department in the Ministry of Environment. It is essential to identify and involve these external stakeholders from the outset of the development of the WSP. Other stakeholders that may be considered at this stage are:

- Community/user groups. The users of the supply (and also the non-users) are the critical stakeholder in the water safety plan, as they suffer the direct results of poor water quality.
- The health sector. The health sector would generally be expected to play some role in the development of health-based water targets, in some independent verification of water quality and monitoring health in relation to water supply
- The water sector planning agency. It is likely that the utility will not be responsible for overall sector planning but that there is some other agency that performs this role.
- Water resource management agency/environmental protection agency. Some of the key supporting programmes related to a water safety plan involve improvement of environmental protection and proper allocation of water resources.

What are the stakeholders' existing responsibilities?

Once all the internal and external stakeholders have been identified, it is important to identify the specific activities in which each of the stakeholders are involved. The first stage is to list all current activities that are being undertaken by each stakeholder. This can follow a format similar that outlined in Table 3.2.

From the list of activities, the key 'stakeholders' in relation to the quality of drinking-water can be identified. In order to define their specific roles an activity-responsibility table can be used. The format of this tool follows the example outlined in Table 3.3.

This stage of analysis is designed to provide an overview of the institutional responsibilities. It is not designed to produce a detailed description of individual stakeholder responsibilities. Results from both Guntur and Kampala indicate that various stakeholders are involved in existing water quality monitoring and surveillance.

Table 3.2. Stakeholder activities

Key activities		**IPM**	**CBOs**	**GOI**	**GoAP**
Water quality surveillance					
Independent collection of samples	✓	✓			
Analysis of surveillance samples	✓	✓			
Analysis of water system related disease events					
Implementation of investigations	✓	✓			✓
Documentation & dissemination of findings	✓	✓			✓
Water quality control (general)					
Agree water quality control strategies		✓			✓
Implement water quality control plans	✓	✓			
Collect water quality samples	✓	✓			
Sanitary surveys	✓				
Regulation					
Develop and agree water quality control targets and standards		✓			✓

Where: IPM = Institute of Preventative Medicine, CBOs = Community Based Organisations, GOI = Government of India, GoAP = Government of Andrapradesh

Source: Chary et al., 2003

Table 3.3. Stakeholder activities					
Activity	**Stakeholders** **Responsibilities**				
	NWSC/WQCD	OSUL Operations	NWSC Operations section	NWSC/Gaba treatment plant staff	Ministry of Health
Water quality monitoring	R	A	A	I	A

Where: Responsibility in each category is marked as R, with involvement as I and awareness of the activity as A

Source: Godfrey et al., 2002

SWOT analysis

After identifying the major stakeholders, it may be necessary to evaluate the capacity of the stakeholders with respect to risk assessment of the piped water supplies. One common method would be to carry out a SWOT analysis: which aims to map out the strengths, weaknesses, opportunities and threats of each of the stakeholders with respect to establishment of water safety plans. The SWOT analysis should be undertaken for each of the stakeholders participating in the steering group. The analysis is of the stakeholders (not the individuals) involvement in water quality monitoring and surveillance. An example of the SWOT analysis undertaken in Guntor, India is outlined in Table 3.4.

Promoting the WSP?

As the WSP is a new approach and is a radical departure from conventional water quality monitoring, careful project preparation is required. Initial steps require an introduction to WSPs that explains and promotes the approach. This can be achieved by presenting the potential advantages that the adoption of the WSP will bring to the stakeholders. For example in Uganda, presentations were given by consultants to NWSC, OSUL, senior academics and the Ministry of Health. Participants included senior management, water and sewerage operations staff, water quality analysts, academics, epidemiologists and sociologists from the Ministry of Health.

The objective of the presentations is to 'make a case' for WSPs. The presentation can involve a description of current practises for controlling water quality, fundamental changes in the World Health Organisation (WHO) *Guidelines for Drinking-Water Quality* (GDWQ) and then advantages of the WSP approach.

Table 3.4. SWOT analysis	
Strengths	**Weaknesses**
Access to international funding	No separate department for provision and O&M of water supply
Availability of technical and qualified man power	Limited number of connections on a quota basis
Established organization structure	Low tariff rate on flat rate basis and tariff decisions based on political consideration
Continued and smooth flow of communication	Poor quality source water
Good transport facilities	Large unaccounted for water
Opportunities	**Threats**
Availability of advanced technology and application of GIS	Rapid growth of informal settlements
Support in development activities from DFID, HUDCO etc	Interrupted power supply
High level community participation	Limited scope of expansion of the distribution system
Rapid educational and economic development of the city	Unauthorized water connections
Willingness to pay for a reasonable tariff for water	Political interference
Increase in customer awareness	Depletion of ground water levels

Source: Chary et al., 2003

Under the advantages of the WSP, it is important to stress the following:

- Cost saving – by adopting the monitoring and verification process of the WSP a cost saving of approximately 30% was made in Kampala, Uganda (Godfrey et al., 2004)
- Investment planning – Increased monitoring at field level results in clearer prioritisation of system improvements
- Unaccounted for Water (UFW) – Increased field monitoring results in rapid detection and upgrading of leaks
- Health benefit – Studies indicate that quality assurance processes such as WSPs can greatly reduce health burdens (Deere et al., 2001)
- Flexibility – WSPs can be incorporated into existing performance monitoring programmes such as Total Quality Management (TQM) or utility-specific change management programs such as Uganda's NWSC 'S-T-R-E-T-C-H' programme.

Critically, the 'buy in' from both senior and operations level managers at this stage must be achieved as detailed in Document 1 (see Godfrey, S., Howard, G., 2004 *Water Safety Plans Book 1: Planning Water Saferty Management in Urban Piped Water Supplies in Developing Countries* for details).

Who should be involved?

Once the WSP framework has been broadly accepted by the stakeholders, it is essential to form a steering group that will direct and monitor its implementation. Indeed, a key to the successful development and implementation of WSPs is coordination and communication between stakeholders. It is recommended that this is done by forming a steering group that has the sole responsibility for the development and implementation of the WSP. This team should be composed of members from varied professional backgrounds in order to form a balanced interdisciplinary team. As well as engineers and water quality managers, the steering group may include academics, planners, surveyors, sociologists and health scientists. The balance of varied professionals is important to ensure that the water safety plan incorporates financial, technical and social considerations.

In order to set up a variable and sustainable WSP steering committee, it is important to appreciate and map out the inter-organisational and inter-departmental relationships. One way to explore such relationships is through the use of system maps. An example of a system map for WQM in Kampala is shown in Figure 3.1. The map shows that NWSC is the major stakeholder in the management of water quality of piped water systems in Kampala. The system map also shows that although the Water Quality Department (WQD) of NWSC is the main department responsible for the Water Safety Plans, it requires the cooperation of other departments in the organisation. These departments may be grouped under NWSC Headquarters and Kampala Area respectively. These departments need to participate actively or passively in the execution of the Water Safety Plans, as will be detailed in the activity responsibility matrices.

During the execution of the Water Safety Plans, NWSC departments will interact with other organisations. These include Kampala City Council Public Health Department, CBOs and NGOs involved in water and health projects in low-income settlements of Kampala City, the Environmental Health Department of the Ministry of Health, the Water Resources Departmental Laboratory, and last but most important the household units.

The team then need to select a leader to act as the Risk Manager and WSP Steering group leader. This Risk Manager has responsibility for overseeing the success of the WSP. Using results from the SWOT analysis and system map, representatives from the most appropriate stakeholder should be nominated.

To allocate responsibilities to each of the stakeholders, an activity/responsibility matrix should be composed. This should firstly involve the listing of all the key

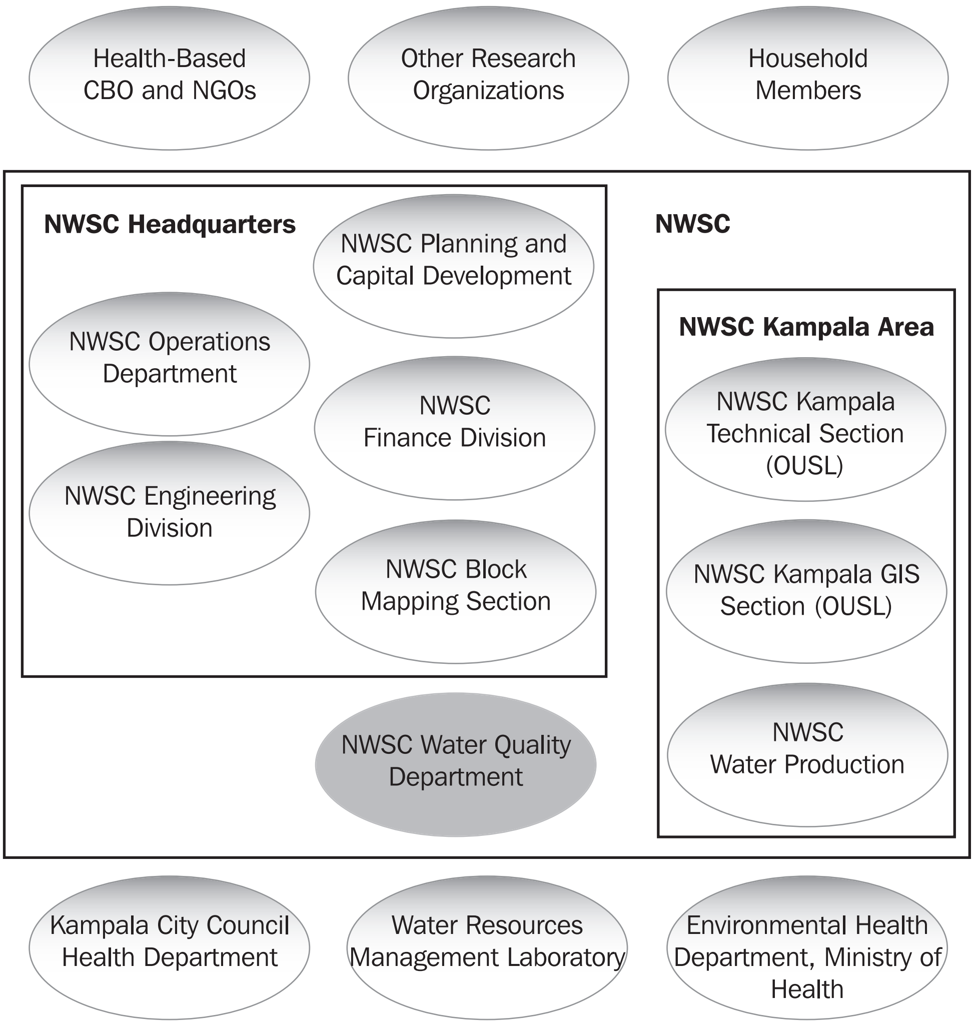


Figure 3.1. System map showing organisations that need to be involved in executing a WSP for piped water supply in Kampala City

Table 3.5. Activity/responsibility matrix					
Activity **Responsibility**	**Utility water quality dept**	**Utility operations dept**	**Utility GIS/ Mapping unit**	**Water production/ treatment dept**	**Planning/ project dept**
Establish utility WSP team	Water quality department to be the lead department	Participate in WSP team	Participate in WSP team	Participate in WSP team	Be aware
Verify system flow diagram	Participate in verification	Lead in verifying system diagram	provide basic maps of system		
Maintain updated of electronic maps of treatment system	Coordinate exercise	Participate in process	Update the flow chart diagrams of treatment processes	Provide updated information on water treatment systems	Be aware
Water quality monitoring	R	A	A	I	A

Source: Kayaga, 2003

activities in the development of a WSP and then the allocation of responsibility for each of these. An extract from an activity/responsibility matrix composed to define roles and responsibilities for the WSP steering group in Kampala is outlined in Table 3.5.

The full version of the activity/responsibility matrix summarised in Table 3.5 is outlined in Annexe 1, (Table A1.1). Table A1.1 provides examples of specific roles assigned to different organisations in establishing the WSP. It follows the 7 stages outlined in Water Safety Plans: Book 1. Additionally, the matrix provides guidance on what key activities are required for involving low-income communities in WSPs, and who should be responsible, and to assign and monitor the role of the regulator. Each of these roles and responsibilities should be decided upon by the WSP steering group through open dialogue.

Once a draft of the responsibility/activity matrix has been finalised, it is recommended that a further presentation is given to senior level management. The objective of this presentation is to share the ideas in the matrix and to seek ultimate approval from all stakeholders on the way forward. The team should then fix dates for periodic meetings to discuss results from the WSP, updates of the WSP, and new system upgrades that require separate WSPs.

Key performance indicators and targets

The steering group should then be responsible for undertaking the key activities to establish a WSP as outlined in Water Safety Plans: Book 1:

- System analysis: desk top description of entire water supply system from catchment to consumer to identify 'risk' points in the supply.
- System assessment: field assessment of selected 'risk' points to identify 'control points'.
- WSP matrix: development of WPS matrices for each 'control point' which includes specific performance targets known as critical limits
- Water quality assessment: field assessment to select appropriate microbiological performance targets for supply.
- Health-based water quality targets: performance targets expressed as Log reductions of selected microbiological parameters.

At each stage of the development of the WSP, consideration should be given to the establishment of performance indicators. These can be considered quantitative means of assessing how an organisation is managing its service provision (DFID, 1998).

A number of methodologies exist for both establishing and reaching performance targets. A typical example is the Total Quality Management (TQM) concept, in which an organisation aims to ensure full customer satisfaction using marketing, process engineering and service provision at the most cost-effective levels. TQM investigates the full scope of product and service 'life cycles' from conception to implementation, through operation and maintenance, and customer service. It depends upon the integration of quality development, quality maintenance and quality improvement efforts of various groups within the organisation. The core values of TQM are:

- Putting the customer first
- Anticipating and knowing customer expectations
- Meeting and exceeding customer expectations
- Getting the service 'right first time'
- Recognising and reducing the costs of poor quality
- Recognising and reinforcing good performance of staff

These core values emanate from a shared and agreed mission statement: that is a corporate philosophy describing the main overall objectives of the service. Once the overall objectives have been determined (where the organisation wants to be), the next step is for the organisation to formulate corporate targets, departmental goals and their respective key performance indicators.

Table 3.6. STRETCH targets for NWSC Water Quality Department, 2003

Target	Present situation	Stretched target
Number of inspection points	40	82
Testing of Cl2 residual	184	218
Sanitary Inspection	0	218
Primary and secondary main inspection points	15	80
Testing of thermotolerant (faecal) coliforms	0	80
Testing of total coliforms	318	0

Source: Godfrey et al., 2002

Regardless of the name given to the process, it is imperative that agreement is reached between all the stakeholders when establishing the performance targets. For example, NWSC has adapted the concepts developed by Dr S. Johnson to stretch the performance of an organisation. To establish the STRETCH targets, NWSC first of all defined S-M-A-R-T targets (targets that are specific, measurable, achievable, realistic and time-bound). These targets were superseded in a subsequent change management programme, hence formulating S-T-R-E-T-C-H targets. Activities of this research project were fully integrated in the NWSC change programme, and STRETCH targets were therefore established for implementing a WSP in Kampala, Uganda. Table 3.6 outlines an example of monthly STRETCH targets

Risk management

Once the risks affecting piped urban water supplies have been assessed, these risks must then be managed to prevent their re-occurrence. This section outlines guidance on the relevant institutional aspects of risk management. It begins by outlining the institutional roles and responsibilities for implementing a Water Safety Plan (WSP), and then provides guidance on key issues such as communication, reporting results and upgrading of the WSP.

Who should implement the WSP?

Water Safety Plans are essentially a risk management tool. As described by Davison et al., 2002, '*WSPs are a form of quality assurance that relies on thorough management of risks to water supplies*'. By their very nature, WSPs are interdisciplinary and require input from various stakeholders: such as the water quality analysts, operations engineers, investment planners and managers. Within the WSP there are a number of key operational components. This section will outline each of these components and provide recommendations on who should implement each one. Annexe 1 shows a detailed Responsibility/activity matrix formulated for the implementation of WSPs at the end of 2002.

Water quality monitoring and verification

Conventional water quality control relies solely on end-product testing, the collection and analysis of water samples for microbiological testing as the only means of assessing the safety of drinking water. As discussed in Book 1, such approaches are only remedial in nature and provide no quality assurance, which requires a greater emphasis on input monitoring and the control of processes design to produce safe drinking water.

Within a WSP, the complementary roles of quality assurance and quality control are recognised. WSPs place a greater emphasis on the routine and regular monitoring of processes (e.g. chlorine residuals, turbidity reduction through treatment and inspection of infrastructure) by the operators as a means of input control. Quality control is still undertaken through periodic verification of performance through analysis of indicator organisms (primarily *E.coli* but also other indicators such as faecal streptococci and sulphite-reducing clostridia). See Book 1 for a full justification of the monitoring and verification within a WSP

Who should do the monitoring?

Contrary to conventional methods of water quality monitoring, the WSP promotes the use of inter-departmental monitoring. For example, in Kampala, the monitoring is done by zonal engineers from the Operations Department in collaboration with analysts from the Quality Control Department (QCD). The zonal operations engineers are familiar with the location of the risk points in their zone and can undertake rapid remedial measures once a point is in non compliance. They are then assisted by the analysts who can explain, record and disseminated the results.

Who should do the verification?

Verification should be undertaken by an authorised and certified laboratory. In the case of utility supply much of the verification can be done by an existing water quality control department as art of their overall implementation of a WSP. Thus, in the case of NWSC in Uganda, the existing laboratories under the water quality control department undertook routine verification.

A further step in the verification process, should be independent assessment of performance through surveillance. As noted by WHO (2004) and Howard (2002) this approach may be through:

- Independent testing of water quality
- Audit based approaches

The first type of approach has been widely used in Latin America and in many developed countries. However, it tends to be expensive and, more importantly, may have a negative impact on the allocation of responsibility with regard to proof of performance. This approach tends to place the emphasis on the regulator detecting failure rather than the supplier providing proof of compliance (Bartram 1996). The audit-based approach is used in many developed countries, including the UK Drinking-Water Inspectorate, and is attracting increasing attention in developing countries (e.g., Ghana). The benefit of audit approaches is that the primary burden of proof is placed on the supplier to demonstrate compliance.

The regular independent analysis approach is less appropriate for the WSPs as the emphasis is on water quality analysis (WHO, 2004). The audit-based approach is more appropriate for the WSP as it involves less frequent verification, encompasses a wider view of water safety that involves detailed assessment of supply operational records and involves some independent testing.

Who should report the faults?

Reporting of faults is a key aspect of the overall communication and participation process. Although water suppliers are often resistant to the idea of reporting of faults to the public (largely because it is assumed that this entails a significant component of blame), mechanisms for doing so are essential to maintain water safety. In many, and possibly most, instances where water quality has deteriorated, it is the public that are the first to identify the problem. Rectifying the problem is not possible unless the water supplier is aware of it, it's location and the nature of the problem.

Most water suppliers have, in principle, some form of fault reporting mechanism – for instance in Uganda, NWSC encourage consumers to notify them of problems. However, as noted at the start of this section these are often of limited effectiveness, as they may require calling a 'hotline' or require the consumer to visit the utility office and report the fault. This may not be the office closest to the fault, but be a head office with a complaints section or the water quality control office (which is often inaccessible). In many cases, the consumer is required to incur expenditure in order to report the fault, which is usually not reimbursed, thus creating limited incentive for reporting the fault. This may be exacerbated by rude or disinterested staff or by excessive delays in responding to the fault. As many households who actually use the water do not have their own connection, they may feel little incentive to report faults. Furthermore, some faults may not be viewed as problematic by users – for instance, burst pipes may offer an opportunity to access water freely close to the home.

Developing the fault reporting mechanism requires the utility to make a commitment that they value this input from consumers. This may be reflected in the overall commitment to water safety and be included in a statement by the utility. Part of this commitment should be to ensure that faults reported will be followed up and acted upon and to ensure some kind of feedback mechanism takes place.

The utility must then create multiple opportunities for reporting of faults. This should include ensuring that free phone numbers are available and that faults may be reported to any office, although it is recognised that this may only provide opportunities for relatively few households. Other mechanisms should include ensuring that reports can be made to field staff responsible for meter reading and issuing. A key element is building trust; it is important to communicate that the report will be acted upon, this may for instance be strengthened by providing the person reporting the fault with a signed receipt of the fault reported, and on completion of the work, notification that the fault has been rectified.

How are the results communicated?

Internal communication

The communication of non-compliance is an important component of the WSP. This should be done in a structured way and should always involve both the operations manager and risk manager. The operations manager should be notified, so as to approve corrective actions in the system, and the risk manager, so as to decide whether a wider external notification is required.

To facilitate the communication, quarterly meetings should take place with the WSP steering committee. During this meeting results can be shared and discussed and decisions made as to appropriate upgrades of the system. For more urgent interventions, a rapid detection helpline could be established using a mobile phone free phone number. This number can be administered by the risk manager and would receive calls from any identified fault in the system. Each of the identified faults should be mapped on the risk maps following guidance provided in document 3 of this guideline series.

External communication

In addition to communication between different departments within the supplier, communication strategy development regarding water safety is important with a variety of external stakeholders. These include the regulatory body and, perhaps most importantly, with users of the service. Communication with regulators is often a matter of some contention with water suppliers, as they feel they are asked to provide sensitive information to people external to the organisation who are perceived as having inadequate understanding of the circumstances in which data was generated. There is also concern that the volume of information required is not consistent with the level of importance attached to safety. Equally, regulators often suspect utilities of hiding information and of disguising their true performance as a means of avoiding censure and enforcement action.

Notification procedures are common among utilities in developed countries, and may also be found in some water utilities in developing countries. However, the systematic use of ‘boil-water’ notices may not be appropriate in developing countries as this may conflict with existing message regarding household water treatment and may be difficult to achieve for households not directly connected.

Some system of notification should, however, be developed. This should include obvious aspects, such as, notification of local public health authorities of failures in supply that have led to significant increases in risk, but should also include strategies for notification of users. In developed countries, such approaches would include the use of mobile warning units, often using basic strategies such as loud hailers on vehicles travelling around settlements warning of the need to boil water. Many regulators include such actions within the requirements expected of water utilities. This may also be supported by messages spread via the mass media, for instance local and national radio, television and newspapers.

How will the WSP be updated?

The updating of the WSP should be the responsibility of the risk manager. It is recommended that this is done on a quarterly (3 month) basis and should involve two principles activities:

Activity 1: revision of risk points

Based on the results from both the water quality monitoring and verification, the number of risk points should be reviewed every quarter. These results should be combined with information on physical upgrades of the piped water supply.

Activity 2: investment planning

The results from the WSP should be used to predict investment planning in both the water treatment plant and the piped network. By identifying, monitoring and verifying a risk point over a three month period, prioritisation of investment can be given to those sections of supply that remain at high risk. This has the additional advantage in that it can reduce Unaccounted for Water (UFW) at the same time as improving quality of water provided.

Conclusions

This chapter has outlined appropriate methods for both assessing and managing risk in piped urban water supplies. The tools and approaches presented should be used as a guide to enable utilities to develop WSPs for their own piped water supplies.

References

Bartram, J. (1996). *Optimising the Monitoring and Assessment of Rural Water Supplies*, University of Surrey, Guildford.

Chary, S., Sansom, K. (2003). *Overview of Management of Water Quality Control and Surveillance for Urban Water Supply in Andhra Pradesh*. Administrative Staff College of India (ASCI), Hydrabad and Water, Engineering and Development Centre (WEDC), UK.

Davison, A., Howard, G., Stevens, M., Fewtrell, L., Deere., D., Callan, P., Bartram, J. (2004). *Water Safety Plans*, WHO, Geneva.

Deere, D., Stevens, M., Davison, A., Helm G., Dufour, A. (2001). *Management Strategies. Water Quality: Guidelines, Standards and Health*, Fewtrell, L., Bartram, J., (eds), ed., World Health Organisation (WHO), IWA Publishing, London, UK.

DFID. (1998). *Guidance Manual for Water Supply and Sanitation Programmes*, WELL, London.

Godfrey, S., Howard, G. (2004). *Water Safety Plans: Book 1, Planning Urban Piped Water Supplies in Developing Countries*, WEDC, Loughborough, UK.

Godfrey, S., Niwagaba, C., Howard, G., Tibatemwa, S. (2002). *Water Safety Plans for Utilities in Developing Countries - A Case Study from Kampala*, Uganda. WEDC.

Howard, G. (2002). *Water Supply Surveillance*, WEDC, UK.

Kayaga, S. (2003). Activity/Responsibility Matrix for Kampala. WEDC, Kampala.

WHO. (2004). *Guidelines for Drinking-Water Quality*, Geneva, Switzerland.

Chapter 4

Population susceptibility

by Dr Guy Howard, Professor Trudy Harpham, Dr Roger Few, & Sam Godfrey

Introduction

Low-income families tend to have access to water supplies of lower service level and have less capacity to store water (Howard, 2002; Zerah, 2000). Therefore, when contamination occurs in a distribution system, the urban poor are likely to be at greater risk as they are less able to delay collection to allow contamination to pass. This may be a particular problem within intermittent supplies, and may have potentially significant implications for risk management and risk communication.

Low-income areas are often further disadvantaged as many utilities place a lower priority on maintenance and good operational practice, compared to higher-income settlements. Therefore leakage, intermittence and pipe breaks may all be greater in low-income areas. In utility supplies, the reporting of faults by consumers is encouraged as a means to identify and rectify problems. Fault reporting may be through use of dedicated phone numbers or through reporting to (sometimes very specific) offices of the utility. Low-income groups are less likely to have access to these means of reporting, and the cost of reporting is likely to be relatively high in relation to their available resources. This is likely to result in less frequent reporting of faults. This, combined with often higher frequency of fault occurrence, indicates that the utility may need to consider alternative strategies to encourage reporting: perhaps through regular visits by staff to low-income areas. In these areas, in order to be able to improve safety management, the utility will also need to develop a more proactive programme of data collection on localised faults.

Given that low-income households are at greatest risk from poor water supply, WSPs should provide mechanisms and incentives for water suppliers to improve services in low-income areas. This may take many forms, and the exact nature of the response will depend on local circumstances, previous experience and available options. It should be stressed, however, that the WSP should recognise that improving water quality control in poor areas is a priority. Management actions are unlikely to be solely linked to specific technical actions by the water supplier, however, they should also include the training of communities in construction and maintenance of tertiary infrastructure. This relies on the creation of effective two-way communication strategies between utilities and low-income communities.

Use of socio-economic criteria within the WSP

The use of socio-economic criteria within the WSP is important when considering how data will be collected and what measures will be applied. The use of socio-economic criteria is likely to include:

- Identifying susceptible communities as a means of prioritising inspection points within the system where control measures are defined (with associated implication for monitoring);
- Identifying communities where different management interventions may be required, for instance training as opposed to repair and rehabilitation;
- Overall planning of water supply to the population to lead to overall reductions in water-related disease and improve household water security.

The socio-economic criteria can be used to differentiate between inspection points of otherwise similar importance, or may result in changes in priority of control measures at particular inspection points, because, a loss of control will impact on susceptible groups. This would be best done after the risk ranking exercise on the individual hazard events and inspection points had been performed, and should be linked to the use of the maps of the system, describing system vulnerability and sanitary risk. A further score is therefore allocated to each inspection point for population susceptibility. Where inspection points have been awarded the same risk from the ranking exercise, they can be further weighted according to whether they will affect poor or non-poor groups.

The second major use of the socio-economic data is to identify communities where different risk management activities can be undertaken, and where innovative approaches involving communities in water safety management are required. In identifying communities where local activities are required to maintain water safety, the concept of ‘shared’ risk management is introduced. Shared risk management approaches rely on partnerships between communities and water suppliers to identify preventive and remedial actions that will support improved water safety management.

The collection and analysis of socio-economic data is often critical in this process as it assists in the identification of particular communities where the nature of the supply and community indicate that there is potential for shared risk management. It may also be used to prioritise interventions between a number of similar communities, for instance, communities that are very poor may have a greater need for help in water safety management compared to communities which have a higher socio-economic status.

Finally, socio-economic data may be used to support policy-making in relation to reducing overall water supply problems and water-related health burdens. A key component for water suppliers in the delivery of key policy objectives is to ensure that safe drinking-water is being supplied to all the population, including those that are of low-income. By disaggregating data by socio-economic group, a greater insight is obtained of the degree to which water safety policy objectives are being met, and whether additional policy, or strategic guidance is needed to improve performance.

Means of collecting socio-economic data

Socio-economic status can be described using both quantitative and qualitative approaches. It is essential, when incorporating socio-economic data into risk management related to WSPs that the method selected has validity with regard to health outcomes, as the primary function of the WSP is to deliver safe drinking-water through effective management.

- Quantitative methods categorise communities by the proportion of households that have a pre-defined set of characteristics, which are taken to reflect their wealth. Quantitative methods often use data from secondary sources (for example, existing data sources are utilised to define relative wealth), much of which is collected using questionnaires, or through observations. In some cases, primary data (that is, where the utility plans and implements a survey of the population), may be used. This would usually be based on questionnaires and/or observational data. Quantitative data on socio-economic status tends to provide relatively broad descriptions in larger communities, and does not provide detail concerning how communities develop strategies to cope with poverty or water supply. Such information can be useful as a planning tool at the supply level, but would support detailed planning of activities within particular communities.

- Qualitative methods aim to build a more comprehensive understanding of the experience of poverty among households in the community, and provide more detailed information regarding coping strategies and household action. The purpose of such approaches is, therefore, geared towards obtaining information about what it means to be poor from the poor households themselves, rather than imposing definitions from outside. Qualitative data is not usually based on questionnaires, but is collected through a range of qualitative techniques including focus-group discussions, semi-structured interviews, wealth ranking and transect walks. Qualitative data may be from secondary sources: particular studies undertaken by NGOs or Government departments, however, this is more commonly collected as primary data. Although qualitative data can be used as a supply-level planning tool, it would more commonly be used as a means of developing community-level actions.

In selecting the method to be used, it is important to define the objectives for collecting this data, and to use the method that will provide data of the greatest assistance in meeting those objectives. For a water supplier defining a WSP, the principal purpose for collecting socio-economic data is in improving the risk ranking of different control points, and identifying priority communities for risk management interventions. Therefore, the initial data to be collected should allow ready comparisons between communities, and provide readily interpreted information for planning. This implies that it is more likely to be based on quantitative data, probably extracted from secondary sources.

This is similar to guidance on zoning for water supply surveillance in urban areas, where initial assessments of socio-economic status are used as a preliminary planning tool, followed by more detailed data collection on water use and water supply adequacy, within identified priority communities (Howard, 2002).

It is likely to be most effective to use existing data to undertake socio-economic assessments, provided the water supplier is able to clearly define the type of information used in determining socio-economic status, and provided, the data covers the operational area of a water supplier within a particular urban area. Existing data will include poverty assessments carried out by donors and/or Government partners, or NGOs. In developing countries, it is likely that this data will become increasingly available as poverty reduction strategies are developed as the core component of development planning.

Where new socio-economic data must be collected, the water supplier is likely to need to bring in expertise to perform assessments. In this instance, it is critical that the approach used be comprehendible to staff in the utility otherwise detailed assessments may only ever be performed once and never updated or used.

Undertaking socio-economic assessments

Determining socio-economic requires consideration of what constitutes 'wealth' or 'poverty' and what data is available on which to base a socio-economic assessment. Although household wage/income is often seen as the easiest way to define wealth, in reality this is unreliable in many situations and may have only limited impact on the household ability to obtain goods and services. Very often other forms of income and the ability to acquire goods and services through influence are more important than the monetary income obtained. Furthermore, data on income is often either lacking or unreliable. Consumption expenditure data (i.e. how much is spent in acquiring the goods and services obtained) is often preferred to income measures. However, the cost of collecting this data is often high and relatively complex. Therefore, although useful in describing socio-economic status, such approaches are unlikely to be widely used.

Using proxy variables for household incomes or consumption expenditures

It is useful in establishing socio-economic assessments to use proxy measures for 'wealth' which reflect income/expenditure relationships. Such data is often included in household surveys and census information and, therefore, can be used to develop an overall assessment of socio-economic status. Many studies collect a disparate set of indicators in the hope that, when taken together, they will provide a representative index of socio-economic status. It is important to note that no 'best practice' has yet emerged with regards to the selection of proxy measures.

One key issue that has arisen in applying these approaches to water supply is that access to water supply and sanitation is commonly included within assessments of socio-economic status. This creates a potential problem for the water sector as there is a danger of 'double-counting' the effect of water on poverty and health. It is recommended that measures of access by service level to water supply and sanitation are considered separately from other factors included within the proxy variables to define relative wealth. In this way, an objective view of both poverty and access to water services can be developed and employed, and used within the risk management framework. Thus, for instance, the water supplier may wish to differentiate between different poor communities on the basis of proportion of households with particular levels of service. Experience has shown that in developing countries, some poor communities within urban areas show significant variation in the proportion of households with access to water supply at or within the home.

This information can be of particular value for the water supplier in terms of developing programmes of shared risk management in low-income communities and investment planning. For instance, in areas with high levels of communal service level use, the water supplier may find shared risk management much easier than in areas where most households have their own connection.

The use of proxy indicators can consider many different attributes of income and expenditure. In some cases, data on aspects of non-essential consumer goods are included as these can be sensitive indicators on relative wealth. Items such as ownership of a TV, radio, car, bicycle and foam mattress have been used in water-related studies and proved effective in identifying relative wealth (Morris and Parry-Jones, 1999). Whilst these approaches have proved effective, there may be problems in relying on this data unless regular surveys are to be undertaken by the water supply utility. In many developing countries, the rates of acquisition of consumer goods is now rapid as prices reduce or become more affordable in relation to income.

In studies in Uganda to develop a socio-economic index for city-wide comparisons of poverty, housing and demographic characteristics rather than consumer durables were used to define socio-economic status (Howard, 2002). This socio-economic index was based on six key variables that described socio-economic status, including roof and floor material, average household size, persons per room, source of livelihood and educational attainment. This index was then combined with two other sources of data, population density and 'water economy' (a composite measure of household connection rates, access to different water source types and patterns of water source use among the poor). From this matrix, each part of an urban area could be categorised in relation to its relative wealth and vulnerability to disease. An analysis of the priority accorded to each category in comparison to the number of cholera cases identified in the 1997/98 outbreak, showed a strong relationship and indicated that the method was robust (Howard and Bartram, 2005). Furthermore, by using a variety of data types, it was possible within the overall framework to remove certain items and allow a differentiation by population, water economy or socio-economic status to be considered in relation to overall poverty.

The original assessment in Kampala was subsequently updated using a rapid field assessment methodology. In the updating, a smaller number of variables were selected that all related to observable housing characteristics (house type, roof and wall materials). The updating was done in two ways. A series of interviews were held with key staff to determine which parts of the city had seen a significant change in socio-economic condition since the first index was prepared, and which areas showed sufficient variation within them to make sub-division important. As the original index had been defined on categorising individual Parishes, this remained the unit of study in the re-assessment. Sub-division was only considered where it could be shown that there was a discrete population within the Parish that lived contiguously and made up at least 30% of the Parish area.

A field study was then undertaken of representative clusters within each Parish to define what changes had occurred based on the three variables selected. Where the study showed that there was a change based on the field assessment, the Parish was reassigned to a new socio-economic category. Where the field study supported sub-division of the Parish, this was demarcated and the different socio-economic status of the different parts of the City defined.

This re-assessment proved relatively simple, but illustrated some difficulties. The major problem was found in directly transferring updated data based on three variables into a larger index containing six variables. This suggests that to update the index, it is preferable to re-calculate socio-economic scores for each area in the City using all six variables when new data becomes available. Another problem that emerged was limited spatial awareness among people consulted regarding definition of Parishes that may require sub-division. This was an expected result and highlights the advantage of using approaches that have quantifiable data on areas with well defined and accepted boundaries.

One recommendation from the field team was in the updating of quantitative indices used, a more qualitative approach may be more viable (particularly in relation to sub-divisions of particular areas). Whilst attractive, concerns over using this approach remain, for instance, there would be a problem of assessor bias over what constituted low and very low-income, which is difficult to reduce.

There was some concern over the lack of change in socio-economic status identified in the field assessment, which led to questions regarding the validity of the approach. However, this is perhaps not an unexpected result as the index was a measure of relative wealth and not an absolute estimation of wealth. Within the context of Kampala, by 1991 the areas that were likely to be developed were already being sought after and built upon. Furthermore, change maybe expected only where there is considered to be some kind of 'gentrification' of low-income areas, which had not occurred in Kampala, where areas that were very low or low income remain largely unchanged.

There was only limited sub-division, probably because the level of significance (30% of the Parish area) was relatively high. However, it is also important to note, if the purpose in collecting information on socio-economic status is primarily as an initial assessment tool, it is doubtful that micro-level differentiation is worthwhile. This is particularly the case where the city contains large numbers of poor communities. The size of area considered suitable for sub-division should be reduced as the overall numbers of poor communities reduces.

A second study, in India, focused solely on households who used piped water supplies. The first proxy of socio-economic status to be used was occupation. In answer to an open-ended question on occupation of head of household, 84 types of activities were named by respondents. Indian social scientists regarded it important that local people classify the occupations according to social standing. Six judges (randomly selected members of the community but not respondents) were selected. All were educated between 5th and 10th class, were male and married. They were individually asked to give a score between 0 and 10 for each occupational category named according to perceived social status. Five categories were ultimately used in the analysis:

1. Unskilled labour (head loaders, casual labourers, harbour labourers)
2. Skilled labour (carpenters, goldsmiths, fisherman, plumbers, electricians, mechanics)
3. Employed (by private or public sector who have wages and an assured job) up to class 4 in Indian classification of government employment
4. Business (self employed in small business - rag dealers, scrap iron merchants, tea shop owners, petty shop keepers)
5. No specific job (unemployed, domestic help)

Other variables were measured which potentially could have been used in a socio-economic status index, but which were not analysed (for example, persons per room, average rooms per family, ownership of dwelling, whether the dwelling had a separate kitchen, type of roofing, electrical connection, whether the dwelling had a separate washing room and separate lavatory). The latter variables were used in purely descriptive ways to profile the population, as opposed to being used in a composite index of socio-economic status.

The choice of approach in collecting socio-economic data varies according to the type of data that is readily available, skills available to the utility in social surveys, and to a significant extent, the orientation and philosophical position of the available researchers. There is no particular method that can be said to be always superior. The major considerations should always be the validity of the poverty measure to health outcomes, and the need for assessment tools that permit initial differentiation of the population, with in-depth poverty and coping strategy analysis performed only in selected communities at a later date.

Rapid assessments

The discussion above has mainly focussed on data collection activities that require fairly substantial surveys. Are there more rapid methods which can be used in assessing socio-economic status within water supply situations? There is now extensive experience of assessing wealth, or socioeconomic status in a rapid way (IIED 1992). A variety of these rapid methods are considered below. However, some important considerations apply to all of the methods.

- **Characteristics of participants** - Is there a balance between age, sex and socio-economic status? Is it culturally acceptable for people of lower status to speak openly in front of those of higher status?
- **Characteristics of field workers** - Do they have experience of participatory work and are they of appropriate sex and age?
- **Location of activities** - Is a neutral place used to enable participants to feel comfortable?
- **Expectations of participants** - Do they understand that this is a data collection exercise or are they expecting any benefits?

The first method to be considered is participatory wealth ranking (PWR). This offers a method for communities themselves to define who the poor are, therefore, providing a more holistic and people-centred determination of poverty and its ranking (Falkingham and Namazie, 2002; Bilsborrow, 1994). The ranking is based on the subjective views of the people in a community who generate their own criteria with which to rank poverty or wealth. The ranking takes place in three stages: mapping, reference groups and analysis (Grandin, 1998).

Mapping: A community meeting is set up involving representatives from all areas of the village. A village map is then drawn and a list of households generated from the map. Each household is then represented by a card.

Reference groups: Three reference groups are set up for each section of the village that has been mapped, with three to five members of the community in each group. Each group then meets separately and sorts the household cards into piles according to wealth on a continuum from high to low.

Analysis: The results of the ranking of the different reference groups are brought together and the piles are scored. The final score of each household is the average of the ranks given by the three reference groups. (Falkingham and Namazie, 2002)

Wealth ranking of each household is time consuming. However, it can also be done for blocks or groups of households.

A less specific method is **village or slum mapping**, whereby, a group of participants draw a single map indicating characteristics of interests (for example, location of public taps, community latrines, wells, groups of high risk individuals and non-users of services). If drawing materials are limited, then maps can be drawn on soil, sand or mud, using sticks, leaves and stones to indicate various facilities and groups. The effectiveness of this method depends upon the ability of participants to spatially conceptualize their community and then draw a map.

Physical transect walks involve a facilitator accompanying selected members of the community as they walk along a defined path through the area concerned making observations about the socio-economic status of households on route. Observations of socio-economic status can be based on housing materials (for example, roofing and wall material), and/or general quality of infrastructure (for example, roads, drains). Several different transects, or lines, need to be taken through the community in order to get a representative picture.

Another rapid method which can illuminate the dynamics of socio-economic status is **seasonality calendars**. A group of participants discuss monthly changes in the characteristic of interest. For example, are some households particularly vulnerable to flooding at certain times of the year?

Another method, which similarly addresses the changing nature of phenomena, is **historical transects or timelines**. This method essentially extends the seasonality calendar to a number of years in order to identify longer term changes.

In order to understand how a particular level of socio-economic status affects susceptibility, the methods of **role play** and **individual diary** may be used. Role play requires a member of the community to imagine the problems faced by a vulnerable person in relation to, for example, accessing water and sanitation. An individual diary documents one day in the life of a low-income individual and highlights the time and effort required to access water and sanitation.

Ideally, a mixture of more standard, time-consuming methods together with these more rapid, participatory methods should be used. But, in situations where resources are severely constrained, the use of rapid methods alone is often the only possibility.

References

Bilsborrow, R. (1994). Towards a Rapid Assessment of Poverty in Van der Hoeven, R. and Anker, R. *Poverty Monitoring: An International Concern*. St. Martin's Press, New York, pp. 150-8.

Falkingham, J., Namazie, C. (2002). *Measuring Health and Poverty: A Review of Approaches to Identifying the Poor*. Department for International Development, London.

Grandin, B. (1998). *Wealth Ranking in Smallholder Communities: A Field Manual*. Intermediate Technology Publications, London.

Howard, G., Bartram, J. (2005). Effective Water Supply Surveillance in Urban Areas of Developing Countries, *Journal of Water and Health*, Vol 3, pp. 31-43

IIED, (1992). Special Issue on *Applications of Wealth Ranking. Rapid Rural Assessment Notes No. 15*. International Institute for Environment and Development, London.

Morris, N., G., Parry-Jones, S., (1999) The Affordability of Water in an African Town, *Journal of the Chartered Institution of Water and Environmental Management* 13: 1-6.

Section 2

Supporting programmes

Chapter 5

Community perceptions and interactions

by Professor Trudy Harpham, Dr Roger Few, & Sam Godfrey

Introduction

The previous chapter addressed issues of how measures of poverty and population susceptibility can be incorporated into the risk management framework. It dealt with issues of how to measure static characteristics of populations, like housing quality, socio-economic status and gender. This chapter turns to the knowledge, attitudes and practice (KAP) of populations. Community perceptions and demands for water safety need to be incorporated into the risk management framework. In addition, it is often useful to assess the potential for community- based actions. Surveys which attempt to measure these issues are generally referred to as 'water user perception studies' and have been used, for example, in various cities and towns in India. These studies need to be linked to Stage 1 of the Water Safety Plan, which is when confirmation that users are committed to the WSP is required. This usually involves assessing whether residents are able to anticipate the potential benefits of the WSP. In addition, water user perception studies need to be fed into Stage 5 of the WSP: which involves the development of the risk management matrix. A water user perception study can assess whether the community is willing to be involved in risk management, and if so, what their roles and responsibilities might be.

The objectives, methods, presentation and use of results in water user perception studies are considered below.

Objectives

Community water safety plans involve a shared risk management approach between communities and utility organizations. The role of community members can include monitoring distribution points, collecting and testing samples, undertaking sanitary surveys and providing general feedback. Before involving communities in these activities, it is necessary to understand community perceptions about:

- levels of service,
- water quality, and
- potential for community involvement.

These three issues commonly form the main objectives of a water user perception survey. Although it is often tempting to widen the objectives of a community survey, it is advisable to limit the extent of the objectives in order to maintain the survey's cost effectiveness.

Methods

It is generally accepted that a combination of quantitative and qualitative methods is the best way to assess knowledge, attitudes and practice. Quantitative data is needed to illustrate the extent/coverage of a phenomenon (for example, boiling water before drinking). Qualitative data is needed to obtain a more in depth understanding of certain behaviours and attitudes (for example, why people boil water before drinking). The methods proposed here are a quantitative household survey using a questionnaire with mainly closed questions and focus group discussions (FGDs).

One of the first issues to be considered is sampling. The quantitative household survey may use either purposive or random sampling. The latter is always preferable, but, in situations where lists of dwellings do not exist, there is a need to

Box 5.1. Kampala water user perception study – sampling

Communities selected: Kalerwe and Banda: each community has approximately 11,000 population; high-density; over 80% renters; majority work in informal sector; low-income; semi-permanent shanty dwellings; lack of drainage.

Selection of dwellings within communities: two hundred dwellings (approximate 25%) were listed from each of the two communities. Of these, 59 dwellings sampled from Banda and 141 dwellings from Kalerwe.

Selection of respondent from sampled dwellings: head of household.

Response rate: 100% as households were revisited until response gained.

Box 5.2. Kampala water user perception study – questionnaire content (continued

Interviewer name:

Date:

Parish:

Zone:

Respondent characteristics (sex, age):

Level of water service (tap in home, public tap, public tank, buy from neighbour, other):

Use of water (drinking, bathing, cooking, animals, gardening, cleaning house, laundry, other):

Other water sources (protected spring, unprotected spring, well, borehole, rain water harvest, other):

Reasons for choosing utility supply (quality, proximity, reliability, availability, only source, cost, other):

Awareness of water treatment (disinfection, filter):

Perceptions of issues important in water quality (colour, taste, clarity, smell, ability to dissolve soap, bacteria free):

Household treatment of utility water (nothing, boiling, filtering):

Storage of drinking-water (plastic can, bucket, tank, filter, other):

Awareness of risks to drinking-water supply (close to latrine, leaking pipe, hose pipe connection, other):

Timing of any observed change in water quality (particular day of the week, evenings, mornings):

Willingness to participate by: attending meetings, providing information, reporting leakages, monitoring, other:

form a list of dwellings, which acts as a sampling frame, from which dwellings can be randomly selected. This is expensive and time consuming. Purposive sampling involves a non-random choice of households, but, is considered a weaker design as results cannot be extrapolated across the wider population. Box 5.1 outlines the sampling for the quantitative household survey of water user perceptions in Kampala, Uganda.

Particular care needs to be taken regarding the selection of the respondent in the household. A mix of gender and age is useful: this may not be possible if household heads are selected as the respondent (in Kampala, 80% of heads of household were male).

Sampling for focus group discussions should aim to select no more than 10 participants per group. The nature of the participants should not be so diverse as to inhibit participant contribution (for example, young females may not feel at ease giving their opinions in the presence of older males). The location of the FGD should be on neutral territory (for example, not at a building owned by the utility). Tape recording of FGDs is advised but transcription of tapes is discouraged as this is very time consuming.

Box 5.3. Kampala water user perception study – FGD content

Introduction of the group participants

Introduction of the concept of water user perception

Objectives of the FGD

Social stratification and daily economic activities engaged in by each individual

Sources of water in the community and reasons for household choices

Affordability of water in community and awareness of utility tariffs

Problems with community water and sanitation

The nature of land ownership in the community

Suggestions to improve the utility's service delivery

The next issue to be considered is the **content of the questionnaire and the FGD guide**. Box 5.2 indicates the content of the Kampala questionnaire and Annexe 2 presents the full questionnaire.

Box 5.3 provides the focus group discussion guide used in Kampala.

The time needed for fieldwork depends on the level of experience of the fieldworkers. and training should be given a priority where necessary (several days should be allowed for this). In Kampala, the data collection process alone took 7 days.

Data analysis requires the use of a statistical software package, like SPSS, for the manipulation of quantitative data, and a thematic/categorical analysis of the notes and tape recordings from the FGDs is necessary. If SPSS is not available, a package like EpiInfo (available free from the World Health Organization) can be used. The first analysis should be a simple frequency distribution, presenting the percentages of the key variables from the questionnaire. This descriptive data is often the type of results that are used most frequently by policy makers and planners, so, should not be overlooked. The next stage of analysis can involve some simple correlations and associations between results that show interesting patterns from the frequency distributions. At this stage, associations with socio-demographic variables can be interesting (for example, are there different perceptions between men and women?).

Presentation and use of results

The presentation of results needs to be reader friendly and succinct. Raw data output from a statistical packages such as SPSS should not be presented. Results should be clearly related to the objectives of the survey.

Box 5.4 presents highlights of the results from the quantitative survey in Kampala.

A text accompanying the quantitative results should discuss general patterns and any surprising findings. For example, in Kampala, the fact that the majority of low- income residents boil the utility water before use was surprising. This could potentially negate the reasoning for developing WSPs in the first place.

Whenever possible, qualitative results should be linked to quantitative results. Sometimes conflicting results will be obtained from the two methods. In this case, both sets of data should be clearly presented.

Box 5.4. Kampala water user perception study – highlights from quantitative results

76% of respondents use the utility services;

34% draw their water from a public tap, 18% buy from neighbours, 24% get water from elsewhere;

58% use utility water for drinking, cooking and bathing;

5% use utility water only for drinking;

Other sources of water are protected springs (66%), rainwater (17%) and unprotected springs (4%);

Reasons for using utility water are quality (100%), proximity (43%), reliability (15%);

57% were aware of utility filtering but only 20% were aware of disinfection;

Water quality issues were dominated by colour and taste (62%), but 9% were concerned about bacteria and 6% the ability of water to dissolve soap;

62% boil utility water before consumption;

75% use plastic cans for storage while 21% have water tanks;

90% of respondents considered latrines as a risk to water quality;

56% committed to attend community meetings, 18% were willing to report leakages and 5% were willing to monitor.

Common themes emerging from the Kampala FGDs were: the relationship between residential tenure and willingness to invest in permanent water connections; the suspicion of water contamination and the associated need for boiling; lack of knowledge about utility treatment of the water supply; the constraint of having a low income and the associated inability to pay new connection fees; the perception that tap water is expensive and the expectation of government or nongovernmental organizations' subsidies.

The results presented above are not disaggregated by any social group (for example, age, sex, wealth). If the sampling design permits such differentiation, then, the presentation of perceptions by socio-demographic characteristics is desirable.

One of the most important parts of a water user perception survey is the **recommendations** emerging from the results. It is particularly important that recommendations can be tracked back to actual research results. Recommendations are likely to provide a direction for utility public awareness campaigns. Also, specific suggestions for community involvement are likely to arise from water user perception surveys. In the Kampala survey, one of the recommendations was that the utility should establish toll-free phone lines for easy reporting of leakages and bursts on the water lines. This emerged from the fact that residents were very concerned about leakages and were willing to report them, but they were reluctant to spend their limited resources in making phone calls to the utility. The Kampala survey also identified the need for the utility to raise community awareness of the water treatment processes.

In addition to a standard survey report, it is recommended that at least two other forms of outputs are produced. Firstly, a **policy brief** is needed for senior officials. This should be no more than two pages long and should include highlights of results and recommendations for action. Secondly, some form of **feedback to the community** will enhance community-utility relations. Feedback can be verbal, diagrammatic or in the form of a short report depending upon the cultural context.

Chapter 6

Development of risk maps

by Sam Godfrey & Dr Guy Howard

Introduction

Risk assessment of infrastructure associated with microbial contamination is a complicated task, for two primary reasons; firstly, multiple variables contribute to risk, and secondly, the information to define those variables is not always available. This is of particular importance in relation to piped distribution networks, as they are 'underground' assets that present high levels of uncertainty. For example, in the application of risk models to a London distribution system by Ta (2002), high levels of uncertainty were noted as information on pipe material and age was not available. As an alternative, the age of houses, roads or land tenure records in the vicinity of the pipes were used to predict the age of the buried pipelines.

This level of uncertainty was further noted by Woodward et al. (2001) in a study of the risk of piped distribution systems to bursts. Here they state that 'until recently there has been limited understanding as to why mains fracture occurs. A number of different factors such as ground movement, rapid changes in air temperature, traffic loadings etc have been suggested as a cause, however the degree to which each factor has an influence on mains failure has not been established'. This is of importance when assessing risk of piped systems to contaminant ingress, as limited information is available both on risk assessment and management of piped water supplies.

To improve understanding of the level of risk to piped supplies, Saegrov et al. (1999) note that mapping is a powerful and valuable tool (Saegrov, 1999). Mapping, notes Saegrov, may include both the use of Geographic Information System (GIS) based systems (which lend themselves to the effective presentation of the varied indicators of risk), and traditional cartographic techniques based on risk assessment. However, as noted by Ta (2002), the majority of literature in risk mapping of piped distribution systems focuses on risk of pipes to bursts and/or analysis in relation to rehabilitation needs/strategies (Ta. 2002). A critical issue, therefore, facing water utilities is in how to develop risk mapping in relation to risk of contaminant ingress. This is of even greater significance in developing countries as there is often limited documented information regarding the system.

During the course of this research the use of maps was identified as being an important aid to develop WSPs. Critical to this was the clarification of indicators of risk, such as pipe vulnerability. The importance of graphically representing these risk indicators to make them more easily understood was noted. The systematic use of maps can greatly assist in illustrating to managers how these risks may vary over time in response to investment. Maps can also identify points of vulnerability with in supply, and indicate how specific sanitary risk of point X in a supply can be monitored and improved. Risk maps are, therefore, a useful tool in supporting and developing risk management techniques (such as, WSPs).

Commercially, there are a number of software packages that are available that could be used to develop risk management maps. These include public domain Geographical Information Systems (GIS) software such as GRASS, commercial GIS software such as ArcInfo, MapInfo, ArcView, CadGIS and network design packages such as AutoCAD. These are discussed in detail in the Geographical Information Systems (GIS) and Risk Models sections developed by Dr Kala Vairavamoorthy during this research.

In the context of the development of risk assessment and management plans, such as Water Safety Plans, it should be stressed that the maps can also be developed, and be effective, without computer software. The use of hard copy maps, for example, with overlaid layers printed/drawn on tracing paper can result in valuable assessment and management of risks in a distribution system.

Risk maps can conceptually be divided into two types:

- **Static risk maps** – static maps detailing inherent risk;
- **Variable risk maps** – dynamic maps detailing variable risk (i.e. changing/ updateable maps).

This chapter will outline two recommended methods in developing both static and variable risk maps. It will outline how to assess high risk points within a distribution system, as well as, how to operationalize the maps to manage risk within the network. The methods presented are:

- **Qualitative risk assessments** – In the absence of a GIS database, these methods enable operators to assess and manage risk in their network;
- **Semi -quantitative risk assessment** – The computation of variable risk levels based on semi-qualitative ranking methods into a GIS database.

The two methods are designed to provide detail on the static or inherent risk associated with the system. A third method using **Modelling based assessments**, such as the use of composite programming to estimate risk weightings for individual variables, is discussed in detail in other documents in the guidelines series.

However, common to all of these approaches is the identification of indicators. These include the identification of pipe attributes and the hazardous environment in which pipes are found. The combination of these variables into a risk matrix, forms the basis for the development of risk maps. The process for developing the risk matrix and recommendations for appropriate risk attributes are discussed in detail in this chapter. In each section, the principles and processes of developing the maps are highlighted with examples of practical applications of the methods used in both Uganda and India.

Risk matrix

Central to the development of risk maps, is the identification of appropriate risk indicators and surrogates that relate to the vulnerability of the water supply. These are commonly termed risk variables: due to their use as single variables within a 'multivariate' statistical method of analysis. They include both the specific attributes of the piped network that result in increased vulnerability of microbial ingress as well as the hazard source or hazard environment in which the vulnerable section of the pipe is located. Risk in the context of ingress into a piped water supply is multifaceted and includes (but is not exclusive) of hazard, vulnerability and susceptibility (Davison et al, 2002).

The development of risk maps assists the Water Safety Plan; it aids the identification of points of risk within the supply and prioritizes areas to control water safety within the system. As pipe networks are underground, risk maps assist the WSP steering group assess and manage surrogate measures of risk within the distribution system. These surrogates may include vulnerability assessments based on pipe material, or hazard assessments using population density as a surrogate of faecal loading. The use of these surrogates helps prioritize which of the pipes is at greatest risk of contamination.

However, levels of information on both hazard and vulnerability in supply will vary according to the extent of data records. This information can be obtained from a number of sources including:

- review of supply records;
- review of maintenance records; and
- sanitary inspection data.

It can also be obtained from an understanding of the relationship between the pipe attributes (material, diameter, age) and the environment in which it is laid.

This chapter recommends appropriate surrogates for assessing vulnerability, hazard and susceptibility within distribution systems. It focuses specifically on the underground assets (i.e. the distribution system) as these require surrogate indicators due to their lack of visibility. The chapter begins with recommendations for appropriate vulnerability indicators and then provides detailed discussion on appropriate indicators of hazards, hazardous environments and susceptibility. The final sections of the chapter details the application of these indicators in assessing risk through three methods; qualitative, semi quantitative and modelling based approaches.

Vulnerability indicators

When determining the risk of contamination in water supplies, consideration must be given to the vulnerability of the piped distribution system. The risk posed by a faecal hazard is dependent, in a large part, on whether the system is vulnerable (i.e. will allow the hazard to enter the supply). Vulnerability is composed of inherent **static vulnerability** and **variable vulnerability**. Static vulnerability relates to the design and construction of the system, and its operation (for instance planned intermittence), that is unlikely to change unless a rehabilitation programme is initiated. Variable vulnerability refers to the operation and maintenance aspects of a system that may change rapidly and unpredictably.

Central to this definition of vulnerability are the physical attributes of the distribution system. Distribution systems comprise of pipes of varying ages, materials, diameters and lengths. Each of these poses a varied level of vulnerability. For example, an old steel pipe may be more vulnerable to failure (due to age and corrosion) than a new uPVC pipe. Therefore, the selection of appropriate indicators for assessing the vulnerability is central to the understanding of the risk posed to the pipe. In order to develop effective surrogates for vulnerability, it is important to assess the varied level of vulnerability based on the pipe attributes. Much of the evidence to support the development of these surrogates is based on evidence from literature

Table 6.1. Indicators of vulnerability		
Category	**Indicator**	**Reason**
Vulnerability indicators	Pipe age	Effects of pipe degradation become more apparent over time
	Pipe diameter	Small diameter pipes are more susceptible to beam failure
	Pipe length and jointing	Long water pipes are more subject to longitude break
	Pipe material	Combining maximum pressure and soil corrosion to indicate different type of material

but should also be routed in practicality (i.e. based on 'expert judgement' of the system). In many water distribution systems however, data may not be available on all of these indicators. In these cases, expert judgement becomes the primary source of information supported by scientific rationale documented in the literature. An example of this would be where no record of pipe jointing methods or materials exists for a distribution system. In this case, consultation with operations staff (for example, distribution engineers) who have knowledge of laying the pipes or of recent repairs may reveal knowledge of pipe jointing methods.

To develop these surrogate measures, Table 6.1 outlines recommended indicators of vulnerability. This is by no means an exclusive list, but based on practical experience gained during this research, these were indicators of greatest significance.

Outlined below is a summary of the key evidence/justification from the literature for the selection of these indicators. The sub sections are divided into the sections of pipe age, diameter, length/jointing and material.

Pipe age

A study by Herz on the relationship between pipe age and pipe failure recognized that the starting point is an analysis of the existing stock of distribution mains (Herz, 1998). The study notes that it is difficult to forecast how long mains will last, and that often, it is dependent on the pipe material. Reliance must, therefore, be placed on historical failure records and predicted survival functions of individual sections of pipes (Herz, 2002).

A rehabilitation strategy for the Teplic Water mains in Northern Bohemia by Herz notes that vulnerability associated with pipe age should consider pipe materials, ages, lifetimes under local conditions, frequency of failures (assumed as 0.5 failures per km per year), losses by leakage and extent of rehabilitation work in the past (Herz, 1998). The research indicated that it is possible to estimate the survival function of different pipe materials in both the short term (defined as lower lifetime) and long term (upper lifetime). These periods are dependent

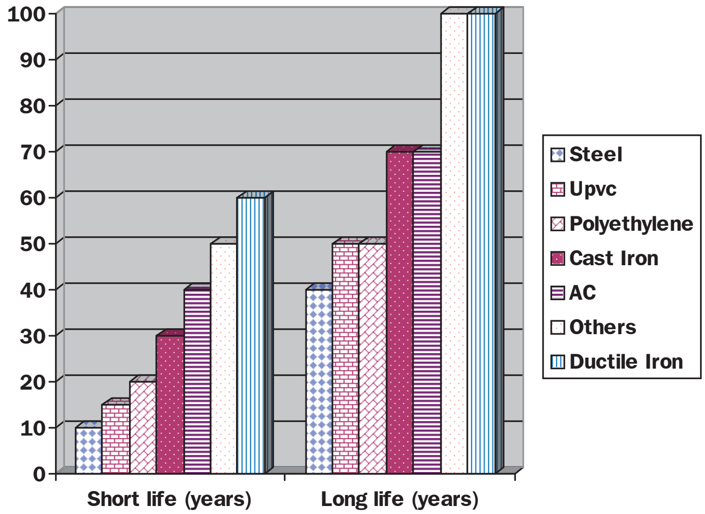


Figure 6.1. Survival function of pipe materials (Herz, 1998)

on varied pipe materials and change over time. Examples of the Herz model are outlined in Figure 6.1.

A detailed study undertaken in Tronhiem, Norway by Lei et al. (1998) further ranked pipe failure using predictive statistical models (Lei, 1998). They developed a descriptive statistical model termed ROCOP (Rates of Occurrence of Failure) and applied it to the Tronheim distribution system. The study came to three main conclusions:

- **Plastic pipe failure** - plastic pipes are the materials most prone to failure (within 5 years).
- **Metallic pipe failure** - metallic pipe is prone to failure after approximately 10 years due to increased corrosion and pitting.
- **Lined metallic pipes** - lined metallic pipes such as ductile iron have a predicted failure life of 40 years.

It should be noted that due to limited on site verification of pipe condition, there is substantial room for potential errors in these methods. Additionally, these criteria were applied with in a temperate European climate and not all conclusions may be applicable to tropical climates. Nonetheless, the study provides a guide and without digging up every pipe within the system it is difficult to verify vulnerability scores associated with each pipe age. Box 6.1, therefore, applies these principles in Kampala, Uganda.

Box 6.1. Use of pipe age attributes for risk mapping – Kampala, Uganda

To apply these models to the Kampala system, an estimation of the percentage lengths of different pipe age and materials is required. In Kampala, using available data and expert judgement, it can be assumed that the network is composed of approximately 60% steel, 20% uPVC, 10% Galvanized Iron and 10% other. The original primary mains were installed between 1930 and 1958 and were made of steel. These were later replaced by Ductile Iron (DI) pipes. The table below outlines the approximate dates associated with different materials and diameters in the Kampala system.

Material	Diameter (mm)	Age	Risk
AC	100	1960	Low
DI	300-800	1958 - 1996	Low
GI	<100	1959 - to date	Medium
PE	<100	1929 - to date	Low/high
uPVC	50 - 250	1935 - to date	Low/high
Steel	50 - 250	1930 - to date	Low/high

Based on the evidence presented in the literature (Herz, 1998; Herz et al., 2002; Ta, 2002), the study in Kampala concluded that pipes laid between 1929 and 1958 were of higher risk than those post 1959 (Godfrey et al., 2002).

A critical component that is overlooked in the risk criteria outlined above is the human factor in quality control of construction work. In many developing countries, pipework does not follow standard codes of construction. This is either because the codes do not exist, are not enforced, or logistically/financially are simply not feasible. As a result, poor workmanship may increase risk regardless of pipe age. Box 6.2 outlines an example of assessing risk of pipe age in Guntur, India with consideration of the human factors.

In contrast to Kampala, research in Guntur concluded that newer pipes (that is, pipes installed since the year 2000) were at greater risk than older pipes (that is, pipes installed in the 1950s) this was for the following reasons:

- Contractors post 2000 use low quality RCC and uPVC pipes due to cost of CI pipes
- High quality CI pipes that were installed in the 1950s used proper installation methods, including the use of appropriate bedding material

Box 6.2. Pipe age and human factors – Guntur, India

The 600km of pipe network in Guntur, India comprises of 60% Reinforced Cement Concrete (RCC), 20% Cast Iron, 10% Asbestos Cement (AC) and 10% uPVC. The original primary main in CI was installed between 1950 and 1952 with network extension in RCC between 1980 and 1983. The table below outlines the approximate dates associated with different materials and diameters in the Guntur system.

Material	Diameter (mm)	Age	Risk
AC	200 - 300	1970 - to date	Medium
DI	N/A	N/A	N/A
GI	N/A	N/A	N/A
CI	300 - 675	1952 - to date	High
PE	N/A	N/A	N/A
uPVC	125	2000 - to date	Low
Steel (ST)	N/A	N/A	N/A
RCC	200 - 1200	1983 - to date	Medium/high

The study in Guntur concluded that pipes laid between 1952 - 1985 were of lower risk than more recent pipes (Prem Chand et al., 2003).

The studies note that although the literature is useful, assessment of the risk of failure based on pipe age must be site specific.

Pipe diameter

Research into the relationship between pipe diameter and pipe failure reveals that larger diameter pipes (that is, trunk mains greater than 300mm) are less prone to failure than smaller diameter pipes. This is due to three reasons:

- **Pipe wall thickness** - increases with pipe diameter. Larger pipes are therefore less susceptible to failure than smaller diameter pipes (Cooper, 2000).
- **Ground movement** - Larger pipes are less susceptible to ground movement from traffic than smaller pipes as they have a greater cementing surface area (Cooper, 2000).
- **Chlorine decay** - Studies of chlorine decay in pipes notes that chlorine decay profiles are most pronounced in small diameter pipes. This is due to increased absorption of chlorine through contact with biomass. Kiene, (1998), estimates that this is most pronounced in pipes with a diameter of less than 75mm.

Pipe length

- The vulnerability of a pipe is directly related to its length. Studies reveal two principal reasons for this:
- **Pipe stress** - Over stressing of pipes is more likely in longer segments of pipe resulting in potential longitudinal breaks (e.g. hoop stress – longitudinal breaks caused by transverse stresses). Studies of vulnerability of varied pipe lengths to failure from earthquake hazards further reinforced that pipe failures increased with pipe length (Ballantyne, 1995).
- **Pipe jointing** - The number of pipe jointings increases with pipe length. Studies of pipe jointing have identified it as a high risk point for potential contaminant ingress. The materials used to join the water pipes, for example seal threaded pipe, should also be considered as possible sites for microbial colonization (Geldreich, 1996). The latter would be of concern as this promotes biofilm formation and consequent chlorine consumption.

Based on the literature, a higher vulnerability score is therefore assigned to pipes of a longer length.

Pipe material

- The American Water Works Association Research Foundation (AWWARF) notes that the selection of pipe material is one of the most important variables in reducing risk of pathogen intrusion into distribution systems (AWWARF, 2002). It is, however, highly complex with many variants beyond the scope of this chapter. Outlined below is a summary of the critical sub variables:

  - Pipe failure – defined as the susceptibility of a pipe material to pipe failure (i.e. breakage). A review of pipe structural deterioration by Rajani et al. (2001) noted that there are three factors that are related to pipe failure. These are:

    - Pipe structural properties (material, quality of installation, pipe-soil interaction),
    - Internal loads (operational pressure, traffic load tolerance),
    - Material deterioration (internal/external biochemical environment).

  - The review by Rajani et al. (2001) concluded that large diameter plastic pipes are more prone to failure than metallic pipes.
  - Pipe friction – This includes the roughness factor within the pipe as defined by the pipes roughness and condition. This is particularly important as a means of defining pipe performance (e.g. high friction rate in AC pipe) and potential of pipe to support biofilm formation (Geldreich, 1996).

- Biofilm - Research by LeChevalier noted that biofilm developed more quickly on iron pipe surfaces than on plastic pipes, due to corrosion and pitting (LeChavallier, 1999). Furthermore, laboratory experiments note a lower biofilm formation rate on uPVC than MDPE pipe (Kerr, 2000).This is of importance as biofilm formation will result in increased chlorine consumption and reduced protection against ingress of pathogens in contaminated water. Biofilm is of primary concern in intermittent systems where pressure surges can result in sloughing (release of biofilm matrix) through the pipe (Geldreich, 1996).
- Chlorine consumption – studies by Kiene highlight a difference between chlorine consumption in synthetic material pipes and that in metallic pipes. The study concluded that chlorine consumption in metallic pipes is greater than in synthetic pipes due to excessive chlorine decay in corrosion deposits (Kiene, 1998). Nonetheless, there is a debate on the relevance of maintaining a disinfectant residual with Payment (1998) concluding that chlorine was ineffectual (with exception of *E.coli*) in the disinfection of more robust microbes (Kiene, 1998; Payment, 1998; Sartory et al., 1997; Servais et al., 1995).

In summary, the literature highlights that metallic pipes are at higher risk to failure than plastic pipes. The literature therefore suggests that metallic pipes are more prone to corrosion and have greater capacity to support biofilm which results in a reduction of chlorine efficacy.

Box 6.3. Risk posed by pipe material – Guntur, India

A vulnerability ranking was calculated for the 4 types of pipe material in the Guntur supply. These included RCC, AC, CI and uPVC.

Pipe material	Failure	Friction	Chlorine consumption	Economic	Vulnerability
RCC	High	High	Medium	Medium	H
AC	Low	High	Medium	Medium	M
CI	Medium	Medium	High	High	H
PVC	Low	Low	Low	Low	L

Where: H = High, M = Medium, L = Low

The study concluded that metallic based pipes RCC/CI are more vulnerable than plastic based pipes PVC/AC as they are more prone to failure, friction and have a medium cost.

Table 6.2. Additional indicators

Category	Indicator	Reason
Operational indicators	Hydraulic pressure	High operational pressure pose a higher risk of pipe failure
	Breakage history	Number of breaks indicating pipe condition
	Leakage record	Leakage condition indicating water pipe condition
	Discontinuity	Frequent pipe empty gives higher risk of pipe break
	Water quality	Water quality can indicate water pipe condition

Box 6.3 outlines an example of applying this risk based principles in Guntur, India. Risk ranking for failure, friction and chlorine consumption was considered for each of the pipe materials in the distribution system. An additional variable of finance was included as this is often a key determinant in the selection of pipe materials in developing countries, and can add to the vulnerability of the water supply.

Additional indicators

As well as vulnerability, operational indicators may also be considered in the assessment of vulnerability. The literature suggests that the indicators outlined in Table 6.2 may also be considered.

Hydraulic pressure

High hydraulic pressure is of concern in many developing countries where aging distribution systems may be affected by intermittence of supply. This is of significance as during intermittence, recharging of supplies occurs, resulting in surging or water hammer effects with in the supply. The older and deteriorating pipes have less ability to cope with surging. Studies by AWWARF in the USA indicate a direct correlation between transient pressure waves and microbial ingress within piped distribution systems. The occurrence of this contamination comes from direct ingress and from sloughing of contaminated biofilm through the supply due to transient pressure waves (Geldreich, 1996; LeChavallier, 1999).

Box 6.4 outlines an example of the significance of hydraulic pressure as an indicator of vulnerability.

Where pressure transient logging equipment is unavailable, a process of monitoring using pressure gauges may be used. If this is not available field visual inspection can provide significant information on areas vulnerable to pipe breakage and discontinuity.

Box 6.4. Balancing water pressure and water quality – Guntur, India

The distribution system of Guntur is supplied by surface water from the River Krishna, treated using conventional treatment at two treatment plants and then distributed through 600km of pipeline. The primary section of the system serving the centre of Guntur town (Zones 1 to 3) was built in the 1950s with the remainder (Zones 4 –10) built from 1980s to date.

The current physical water loss is 30-35% due to pipe leakage. The system is operated on an intermittent basis with each zone receiving 2 hours of supply per day. During periods of recharging of the network high levels of contamination was noted and during periods when the system is flat, ingress of contaminated water into leaking pipes is visible. These result in potential high levels of microbial contamination.

Other factors affecting the vulnerability of water pipes to failure are external. These include but not exclusively:

- Bed condition – Improper bedding may result in premature pipe failure;
- Soil condition – Corrosivity and level of microbial contamination of the soil surrounding the pipe;
- Backfill depth – The backfill soil and soil moisture may vary with depths;
- Traffic loads – Increased potential for pipe failure in areas of high traffic loading;
- Pipe location – Pipe surrounding condition, e.g. in flow of untreated sewage.

Hazard assessment

The degree of microbial ingress at points of vulnerability is also highly dependent on the extent of hazardous material with in the environment. Indicators of hazard are varied, and include both specific hazard sources (such as leaking sewers) as well as hazard environments (i.e. the environment in which a pipe section is located). To develop effective risk maps, hazards affecting the distribution system should be identified primarily in relation to potential sources of hazards that are found above or close to the distribution mains. These may include leaching of contaminants from all forms of sanitation into the soil in water-logged areas.

To achieve this, Davison et al. (2002) recommend the use of hazard events as they provide the easiest way of categorizing hazards that affect the piped water system. This approach has an advantage for identifying indicators of failure in microbial quality, as focusing on potential sources of pathogens allows the diversity of potential pathogens to be included without extensive water quality assessment. Deere et al, (2001). proposed the use of hazard event scenarios that are assessed based on the potential sources of hazard, and the pathways of the hazard, into the water supply. The types of indicators that may be considered are outlined in Howard et al. (2002):

- Proximity of sewer system to water supply: including estimates of the likelihood of cross connections and the relative depth of water supply and sewer pipes.
- Proximity of other forms of sanitation systems.
- Low lying areas (resulting in depressurization of pipe systems).
- Other sources of faecal matter such as animal husbandry.

To define hazardous areas, topographical and sanitation type data may be used. These will include sewer maps, maps of on-site sanitation and topographical maps indicating low lying areas. The identification of low lying areas is essential in determining points where potential ingress or backsiphonage of contaminants may occur.

Where detailed information on sewerage is unavailable, alternatives may be sought such as the use of population as a surrogate for faecal loading. Research shows a strong correlation between population density and quantity of faecal material in the environment (Howard, 2003, Mara et al, 2001). Box A3.1 (see Annexe 3) outlines an example of the use of this method in estimating hazard environments in Kampala, Uganda.

Susceptibility

Susceptibility is important in further categorizing high impact ratings. Susceptibility is defined as low socio-economic status populations that would be most susceptible to health problems if a contamination event occurred. The susceptibility assessment may involve assessment of socio-economic status of the consumer based on quantitative approaches. Alternatively, it may be based on broad-brush qualitative estimates. This susceptibility factor plus the associated risk of the system equals an impact rating (i.e. the potential impact on the population of a contamination event). This is effectively used as an additional tool to assist in planning/scheduling, monitoring and assessment activities to improve water safety.

To achieve this, it is recommended that socio-economic data is collected through field surveys. For example in Guntur, India, rough sketch maps of zones were made based on the relative socio-economic status of the inhabitants of the zone.

Box 6.5. Example of socio-economic criteria in Guntur

In a section where a water pipe intersects a drain (ref. 3DC31) in Mirchi Yard Tank supply zone, the East side of the tank is uninhabited and the West is a low income area. The point is therefore considered to be located in a low-income area based on criteria in the table below.

Category	House type/ roof type	Susceptibility	Risk
Very Low-Income	Huts	High	H
Low-Income	Tiled/Asbestos sheet	High	H
Medium-Income	RCC up to first floor	Medium	M
High-Income	Apartment	Low	L

This process is repeated for all identified risk sections in the supply.

The indicators used to define the socio-economic status included:

- Roof material
- House type

These nominal indicators were observed from the elevated service reservoirs that serve the zone, with sketch maps then being drawn of each zone. This susceptibility factor is then included, based on categorizations of Very Low to High Income, to prioritize sections of risk within the distribution system. Box 6.5 provides an example of how to apply the socio-economic criteria to a distribution system

Measurement of the above indicators provide the basis for estimating risk for individual sections of the distribution system. Each of the variables of vulnerability, hazard and susceptibility should be considered. The following sections outline three methods used during this research for comparing the level of significance of each of these contributing risk variables. The first method outlines a simple process, qualitative risk ranking, which adopts a broad-brush approach to risk estimations in systems with limited available data. The second method provides a more precise method that uses a risk ranking table to provide a semi quantitative estimate of the total sum of weightings for the risk variables. This method gives a more precise estimation of the level of risk associated with individual sections of the water supply using conventional risk ranking methods. Document 3 of the guidelines series then outlines a more complex method of risk ranking based on fuzzy composite programming.

Qualitative risk methods

In distribution systems with little or no data on either vulnerability or hazardous environments, a simple qualitative method of risk estimate is recommended. This system is heavily reliant on expert judgement, and local knowledge, and can provide very accurate qualitative estimates of risk. The process of qualitative risk mapping is one method of sharing this information.

To undertake qualitative risk mapping, the following steps are recommended:

STEP 1: Information gathering – The collection of all existing information on the water supply system. This includes available water distribution maps, topography maps, sewer maps, pipe attribute data, operations data (breakage, intermittence, water quality) and population data. The data should be assembled into layers, using the piped distribution as the platform. Further information can be drawn/plotted onto tracing paper and overlaid onto the pipe platform.

STEP 2: System description – Where maps do not exist, take an A1 sheet of paper and draw a rough schematic design of the water distribution network: starting with the water source and then tracing the water distribution through the treatment works, service reservoirs, supply tanks and primary and secondary distribution networks (see Box A3.2, Annexe 3). This should include detail on supply zones within the network. Where pressure data is unavailable, these can be zoned based on knowledge of existent isolation valves.

STEP 3: Hazard assessment – If maps are available for on-site sanitation or sewerage, these should be used to establish hazardous areas within the network. Specific attention should be given to areas where water mains pass through low-lying or swampy areas. In the absence of maps, expert judgement should be used to identify several areas with sewers, on-site sanitation, low-lying areas and high population density. To develop the map each of these can be plotted manually on tracing paper and overlaid on the schematic design of the network.

STEP 4: Vulnerability assessment – The indicators of pipe vulnerability such as pipe age, material, length and diameter should be established for all known sections of the network. These should be plotted on a third tracing paper layer. Where a database does not exist, expert judgement may be used.

STEP 5: Inspection point – Using a qualitative assessment of the available information, high 'risk' points within the network should be identified. To achieve this, a qualitative risk ranking process is used based on expert judgement of the system. Where information is not available for all the inspection points, expert judgement can be used to decide which point is more critical than another. The points should reflect a representative sample of the entire network and may include points from the primary, secondary and tertiary infrastructure (see Box A3.3, Annexe 3 for an example). The sanitary integrity of each of these points should then be field tested and the 'high' risk points (that is those based on severity of impact on livelihood) selected for further monitoring.

The qualitative method of risk mapping is a 'broad-brush' approach. It is highly applicable for systems with limited data to provide the risk assessor/manager with sufficient data to estimate points of supply at highest risk.

Semi-quantitative risk methods

The process of semi quantitative risk mapping is a more detailed process than the qualitative estimation of risk. It is undertaken in water distribution systems that have reasonable data sets. The minimum requirement for undertaking the semi quantitative risk approach includes:

- Population data;
- Pipe vulnerability data; and
- Historical water quality data.

If this information is not available, and resources are not available to collect the information, it is recommended that qualitative risk estimates are undertaken.

The semi quantitative process uses digitized or electronic maps. These may be in a static format such as AutoCAD system designs or in a variable format such as a GIS package. The process of semi quantitative risk assessment provides risk values for individual sections of the water distribution system. Different to the qualitative approach however, the semi quantitative approach uses risk matrices to estimate risk weighting for each risk indicator. For example, it allows the comparison of the risk associated with a 6" Steel pipe laid in 1960 to be compared to an 8" uPVC pipe laid in 1995. Outlined below are the processes involved in the development of semi quantitative risk maps.

It is recommended that a system of layering is used based on the water distribution network (see Box A3.4, Annexe 3).

The maps should be divided into hazard and vulnerability categories. It is recommended (as in Box A3.4, Annexe 3) that a map of the piped distribution system is used as layer 1, overlaid on this map are the sewer and hazard sources in layer 2 and 3. The vulnerability of the piped network should be estimated based on hydraulic supply zones, with the identification of the pipe attributes, levels of leakage/intermittence and breakage overlaid as separate layers. For each of these categories, it is recommended that a risk matrix is prepared which includes risk ratings for each of the indicators. These may include semi quantitative numerical ratings of 1, 2, 3 or linguistic rating of for HIGH, MEDIUM and LOW levels of hazard. These should be applied to each of the categories and each step of the map composition.

To achieve this 10 steps should be followed:

1. Categorize each 'risk' point as an infrastructure type on the map (e.g. valve box, secondary main etc);
2. Identify location, administrative boundary and hydraulic zone for each point;
3. Record risk score for each hazard and susceptibility indicator in risk ranking table;
4. Identify the pipe number on which the 'risk' point is located;
5. Interrogate pipe attribute database for each point;
6. Record risk score for each vulnerability indicator in risk ranking table;
7. Calculate risk score for each point;
8. Plot risk score for each point on map;
9. Estimate extent of risk on map from one risk point to another;
10. Select appropriate number of risk points of greatest significance.

An example from Kampala following the steps 1 to 10 outlined above is show below. The process begins with how to estimate hazard ranking in Box 6.6 and is followed by a detailed example of what is required to estimate vulnerability and susceptibility, culminating in a risk ranking table in Box 6.7. It should be stressed that the scorings used in the example are specific to Kampala and should not be used as a definitive means of risk ranking. Full details of the risk mapping methods used in Kampala can be found in Godfrey et al., (2002).

Hazard identification

Using existing digitized information, population densities should be calculated using the process outlined in Box 6.6. Scores of high, medium and low population density are used as surrogates for potential faecal loading. To identify the hazardous environments, a digital topographic map of the study area may be overlaid on the

Box 6.6. Hazard ranking – Kampala, Uganda

Only 10% of Kampala's population has access to sewered sanitation. Classification of other sanitation types in non-sewered areas of the city is difficult. Therefore for each category a nominal hazard value can be assigned. This value reflects the relative hazard associated with faecal loading based on population density categories (the higher the population density, the higher the hazard score). Each of the scores refers to a particular parish.

Population density	**Category**	**Risk**
36992-16364	High	4
15974 - 7833	Medium	3
7689 – 3801	Low	2
3716-687	Very low	1

Using maps, the hazardous environment in which water mains are located can then be identified. For comparability of data, the parishes should be used to identify which parishes are located in low-lying areas.

Additionally, those parishes within low-lying areas susceptible to water logging may be assigned a nominal value of 1 (hazardous area) and those parishes outside of the low-lying areas assigned a nominal score of 0 (non hazardous area). Each of these scores can then be computed into a risk score for each point identified within the supply. For example, A standpipe located in the high density parish would be given the following hazard score:

	Hazard source			**Hazard environment**		**Hazard score**
Sampling point	**Parish**	**Population density**	**Risk**	**Low lying (Y/N)**	**Risk**	
Standpipe near Mosque CRN: 2317/556	Katwe	HIGH	4	Y	1	5

pipe network layer. Low-lying areas, sewered areas and areas of on-site sanitation are then identified within the system. For accuracy, the water and sewerage supply should be overlaid electronically and areas of close proximity or where water mains cross sewer lines should be identified. Further information from local knowledge concerning known points of vulnerability, such as location of exposed pipes, faulty valves etc., may also be included.

Vulnerability indicators

The objective of mapping vulnerability within the system is to ascertain which areas of the system with in the highly hazardous areas is at highest risk to contaminant ingress. To do this it is important to understand the hydraulics of the system by breaking down the system into manageable sections or zones. This is based on the hydraulics of the network.

Where a hydraulic model exists for the network, isolation points should be identified and the various supply zones marked as an overlay on the distribution system platform. Where a hydraulic does not exist, expert judgement is used. This includes tracing the flow of the supply from the treatment works through individual service reservoirs to individual zones of supply with in the network. Outlined in Box A3.5 (see Annexe 3) is an example of zoning of the distribution system using expert judgement in Kampala, Uganda.

In distribution systems with available data, information on the vulnerability of each of the risk points should be compiled in a spreadsheet format. It is recommended that this data is organized by pipe number. A system using a number for each pipe that includes the year of installation, followed by I.D. number (such as pipe laid on year 1993, I.D. 05 will be 199305), may be used. For each of these pipe numbers, information on the age, diameter, length, material and jointing method should then be recorded. Recommendations on methods for preparing semi quantitative estimates of risk for each of the vulnerability indicators are outlined below.

Pipe material

First, data on the pipe attributes should be reviewed. The varied pipe materials should then be identified and recorded. These may include; uPVC, Flexible Polyethylene (PE), Asbestos Cement (AC) etc. For each material a risk score for every sub variable identified should be calculated. This includes susceptibility of the pipe material to:

1. Pipe friction
2. Pipe failure
3. Chlorine consumption
4. Biofilm formation

Risk scores should be assigned: based on the evidence presented in the literature. A semi quantitative estimate for the vulnerability of each pipe material can then be calculated, with risk scores for failure, friction and chlorine consumption being added together to calculate the associated vulnerability of each pipe material.

Pipe diameter
A review of the pipe diameters within the distribution should then be undertaken and recorded. Based on the evidence, pipes should be divided into diameters, beginning with small and going up to large diameters. The literature review suggests that larger diameter pipes are less prone to failure due to greater wall thickness and reduced potential for biofilm formation. Lower risk values may then be used for higher diameter pipes compared to lower diameter pipes and recorded in the risk table.

Pipe length
Based on the literature, a semi quantitative estimate of the number of vulnerability scores should be assigned. These may include a low risk score for pipes with a length less than 100m (score of 1), a medium risk score for pipes between 150 and 750m, a high risk score for pipes between 1000 and 2000m and a high risk score for pipes between 3000 and 4000m.

Pipe age
The influence of pipe age on pipe vulnerability can be estimated, based on literature. Site specific quantitative risk estimates should be undertaken which consider material of pipe, frequency of repair and known failure rate. A nominal risk score is recommended: this should be added to the risk matrix.

Susceptibility indicators
This is calculated using socio-economic information based on either administrative boundaries or parishes. This susceptibility factor, plus the associated risk of the system, equals an impact rating (i.e. potential impact on population of a contamination event). To estimate this, existing census data can be used or alternatively rapid assessments of socio-economic information may be undertaken.

Performance data
Other performance data available, such as rates of leakage, breakage or water quality non compliance for each of the 'risk' points, can also be recorded at this stage.

Quantitative risk scoring
Once risk estimates have been established for the above indicators, it is recommended that an overall risk score is assigned to each inspection point within the supply. Using the quantitative risk estimate approach, it is possible to combine all the sub variables to calculate a total risk score. This may follow the example outlined in Box 6.7.

Box 6.7. Semi-quatitative risk ranking table

		SUSCEPTIBILITY			HAZARD				VULNERABILITY										STATIC VULNERABILITY
					Hazard source		Hazard environment		Pipe attributes								Performance monitoring data		
Sampling point	Sampling point category	House type	Roof type	RISK	Parish (POP)	RISK	Low Lying Area	RISK	Length (m)	RISK	Diameter (mm)	RISK	Material	RISK	Age	RISK	Pipe Breakage (p/a)	Discontinuity (p/a)	Leakage (p/a)	
Namirembe booster																			
Namirembe parish	Booster station	VL	H	H	Namirembe	L	N	L		M		M	ST	H		M	L	M	H	M
Pipe number 2209									474		100								

Key
p/a = per annum, VL = Very Low, L = Low, M = Medium, H = High

The static vulnerability estimate outlined in Box 6.7 is calculated for each risk point and is then used to prioritize inspection points to be assessed in the field. Box A3.6 (see Annexe 3) outlines an example of how to apply this quantitative risk estimate approach.

Using the information in Box A3.6 (see Annexe 3), the static risk of individual sections of the distribution system can be estimated. The prioritization of points with in the supply for monitoring will depend on the level of static risk identified. The process of semi-quantitative risk ranking is a useful process for disaggregating available data on piped supplies to form a calculated decision as to points of greatest vulnerability.

References

AWWARF (2002) Chapter 7: Recommended Control Strategies. *Pathogen Intrusion into the Distribution System*. AWWARF.

Ballantyne, D., Dames, Moore, (1995) Relative Earthquake vulnerability of water pipes. Proceedings of 1995 Annual Conference Engineering and Operation, Anaheim, California.

Cooper, N., R., Blakey, G., M., Sherwin, C., Ta, T., White, J, T., Woodward, C., A., (2000) 'The Use of GIS to Develop a Probability Based Trunk Mains Burst Risk Model.' *Urban Water* 2, pp. 97-103.

Davidson A., H., G., Stevens, M., Callan, P., Kirby, R., Deere, D., Bartram, J., (2002) *Water Safety Plans (WSPs)* final draft.

Deere, D., Stevens, .M, Davison, A., Helm G., Dufour, A (2001) Management Strategies. *Water Quality: Guidelines, Standards and Health*. L. Fewtrell, Bartram, J., (eds), World Health Organisation (WHO), IWA Publishing, London, UK.

Geldreich, E., E., (1996) *Microbial Quality of Water Supply in Distribution Systems*.

Herz, R., K., (1998) 'Exploring Rehabilitation Needs and Strategies for Water Distribution Networks.' *Aqua* 47(6), pp. 275-283.

Herz, R., K., Lipkow, A., (2002) 'Life Cycle Assessment of Water Mains and Sewers.' *Water, Science and Technology* 2(4), pp. 51-72.

Howard, G. (2003) PHD thesis. Robens Centre of Environmental Health. Guildford, University of Surrey.

Howard, G., Vairavamoorthy, K., Godfrey, S., (2002) *Improved Risk Assessment and Management in Urban Piped Water Supply - Inception Report*, WEDC.

Kerr, C., J., Jones, C., R., Hillier, U., F., et al. (2000) ‘Statistical Evaluation of Adhesion of a Bioluminescent Pseudomonad to Thermoanox in a Modified Robbins Device.’ *Biofouling* 14(4), pp. 267-277.

Kiene, L., Lu, W., Levi, Y., (1998) ‘Relative Importance of the Phenomena Responsible for Chlorine Decay in Drinking-Water Distribution Systems.’ *Water, Science and Technology* 38(6), pp. 216-227.
LeChavallier, M., (1999) The Case for Maintaining a Disinfectant Residual.’ American Water Works Association 91(1), pp. 86-94.

Lei, J., Suenung, S., (1998) Statistical Approaches for Describing Failures and Lifetimes of Water Mains. Water, *Science and Technology* 38(6), pp. 209-217.

Payment, P., (1998) Distribution Impact on Microbial Disease. *Water Supply* 16(3-4), pp. 113-119.

Rajani, B., Kleiner, Y., (2001) Comprehensive Review of Structural Deterioration of Water Mains - Physically Based Models. *Urban Water* 3, pp. 151-164.

Saegrov, S., MeloBaptiste, J., F., Conroy, P., Herz, R., K., LeGauffre, P., Moss, G., Oddevald, J., E., Rajani, B., Schiatti, M., (1999) Rehabilitation of Water Networks - Survey of Research Needs and On Going Efforts. *Urban Water* 22(15), pp. 15-22.

Ta, T., (2002) A Probability Model for Burst Risk Studies of Water Mains. *Water, Science and Technology - Water Supply* 2(4), pp. 29-35.

Woodward, C., A., Ta, T., Whiter, J., (2001) Risk Analysis related to Water Mains Bursts. *Computing and Control for the Water Industry*. R. Powell, Hindi, K, S., Research Studies Press Ltd, UK.

Annexes

Annexe 1: Additional table
Annexe 2: Questionnaire
Annexe 3: Additional boxes

Annexe 1: Additional table

Table A1.1 Extract of activity/responsibility matrix for a WSP of urban water services using risk management methods – e.g. NWSC, Public managed utility

Activity	Utility water quality dept	Utility operations dept	Utility GIS/mapping unit	Water production/ treatment dept	Planning/project dept
Responsibility					
System analysis					
Maintain updated electronic maps of treatment system	Coordinate exercise		Update the flow chart diagrams of treatment processes	Provide updated information on water treatment systems	
Maintain updated electronic maps of water transmission and supply network showing relevant variables.	Coordinate exercise	Provide data on existing system about pipe sizes, materials, lengths, depths and age.	Update electronic and hard copy maps of reticulation diagrams		Provide data on new projects
Update configuration of supply pressure zones	Coordinate exercise	Carry out pressure tests and update zoning Update configuration of supply pressure zones	Update electronic & hard copy maps	Update treatment plant outlet pressures	

Annexe 2: Questionnaire

NATIONAL WATER & SEWERAGE CORPORATION
KALERWE & BANDA COMMUNITIES

Water User Perception Questionnaire

Interviewer's Name		Date	
Parish		Zone/Ward	

Tick as appropriate

Respondent:

Male ☐ Female ☐ Child ☐

Age of Respondent ☐

Section 1: Level of service/source

1. Do you receive NWSC Services?
   a. Yes b. No

2. What level of service do you receive from NWSC?

LEVEL OF SERVICE	TICK
More than 1 tap in home	
1 tap at home	
Use a public tap	
Use a public tank	
Buy from neighbour	
Others (specify)	

3. What do you use this water for? (Multiple responses allowed)

USE	TICK	USE	TICK
Bathing		Animals	
Cooking		Gardening	
Drinking		Laundry	
Cleaning House			
Others (specify)			

4. What other sources do you use?

SOURCE	TICK
Protected spring	
Unprotected spring	
Scoop well	
Borehole	
Rain water harvest	
Others (specify)	

5. Why do you choose to use NWSC supply instead of other sources? (Multiple responses allowed)

REASON	TICK	REASON	TICK
Quality		Only source	
Distance		Only tap	
Reliability		Personal/Family reasons	
Availability		Cost	
Others (specify)			

6. Do you know what treatment is done to the NWSC Water? N/Y. If yes, what?

REASON	TICK
Disinfection	
Filter	

Section 2: Water quality

7. (Do not read response) What issues of quality do you consider to be of importance? (Multiple response allowed)

REASON	TICK	REASON	TICK
Colour		Ability to dissolve soap	
Taste		Smell	
Suspended solids		Bacteria	

8. Why do you consider this issue of Quality to be of importance?

9. After you have got NWSC water do you do any other treatment? (specify)

FORM	TICK
Boiling	
Post storage	
Filtered	
None	

10. Do you boil your water?
    a. Yes b. No
    b.
    c. If so why?

11. How do you store your drinking water? (Multiple response allowed)

STORAGE	TICK
Jerry can	
Bucket	
Tank	
Filter	
Others (specify)	

12. What risks are you aware of to your drinking water supply? (Multiple response)

REASON	TICK
Close to latrine	
Leaking pipe	
Hose pipe connection	
Others (specify)	

13. When do you see changes in the quality of the Water?

REASON	TICK
Period	
Days of the week	
Evenings	
Mornings	
Others (specify)	

Section 3: Community responsibility and water related diseases

14. What in your opinion causes diarrhoea?

15. Having realized water quality problems/issues – what are you willing to commit? (Multiple response)

RESPONSIBILITY	TICK
Attend meetings	
Provide relevant information	
Report leakage	
Give time for monitoring	
Provide artistic skills	

16. What are the Community roles in combating these diseases?

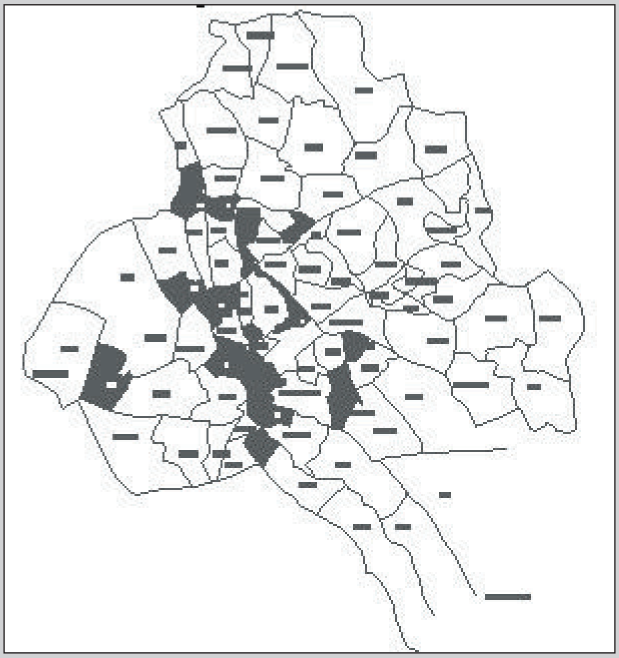
a.
b.
c.

Annexe 3: Additional boxes

Box A3.1. Hazard source - Kampala, Uganda

To model the hazardous environment, parish-level administrative boundaries were digitized as polygons from existing paper maps obtained from the Department of Surveying, Entebbe, Uganda. Using data from previous research and the national census figures (1991) a 4.7% growth rate was applied, the population for each parish was computed. By dividing this estimated population with the corresponding parish area, the population density for each parish was calculated (Howard et al. in press).

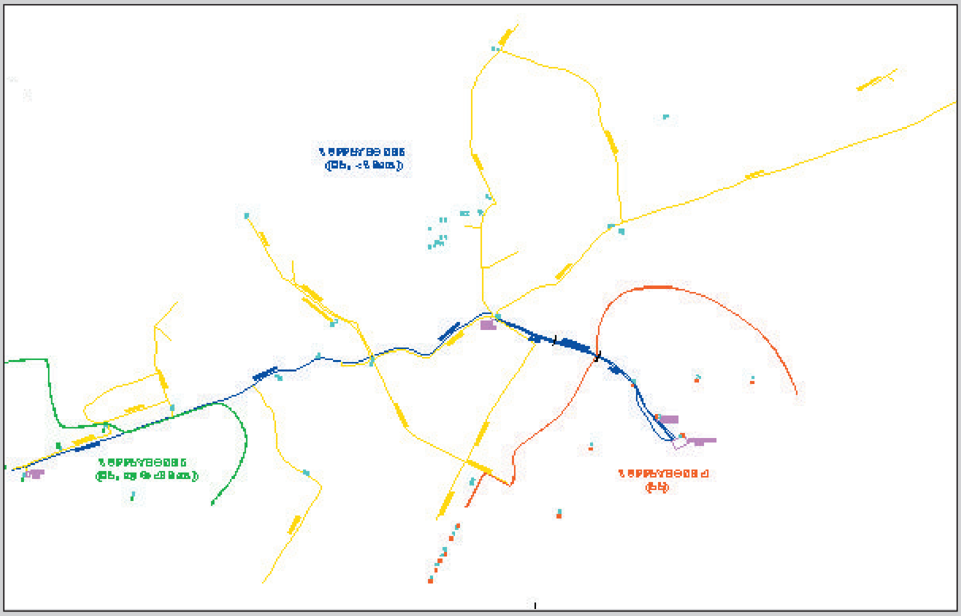
Based on the derived figures, the parishes were categorized by population density into high, medium, low and very low. This information was then thematically plotted onto the parish boundary layer, through colour-coded shading of the respective parish polygons.



The map above indicates the parishes, marked in black, as having high faecal loading.

Box A3.2. Schematic design

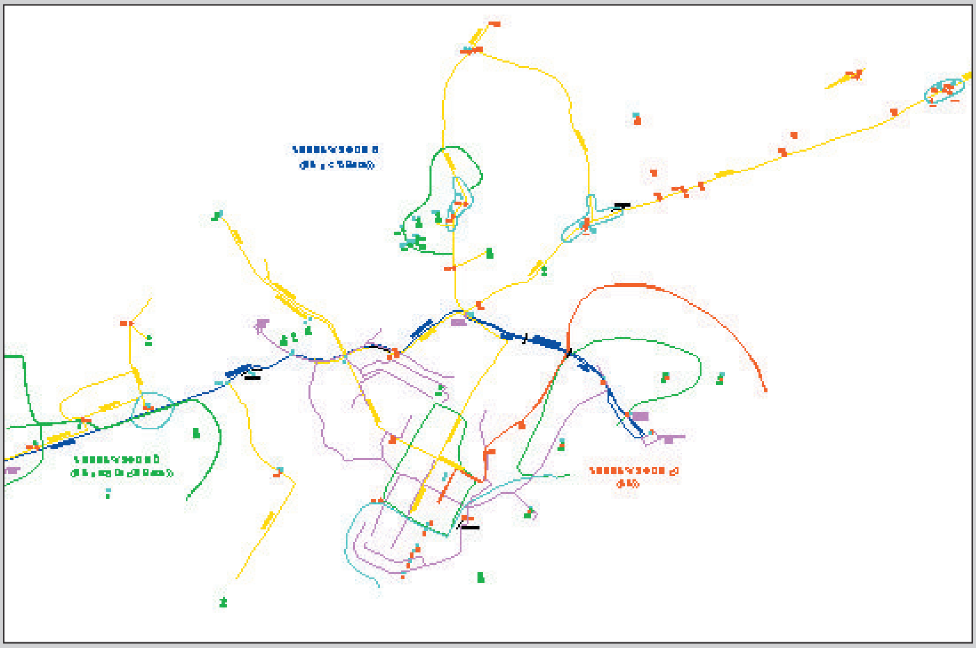
Where maps do not exist, a map of the water supply system can be drawn. Outlined below is an example of where, due to the lack of available digitized information, the system operators sketched a map of the supply system.



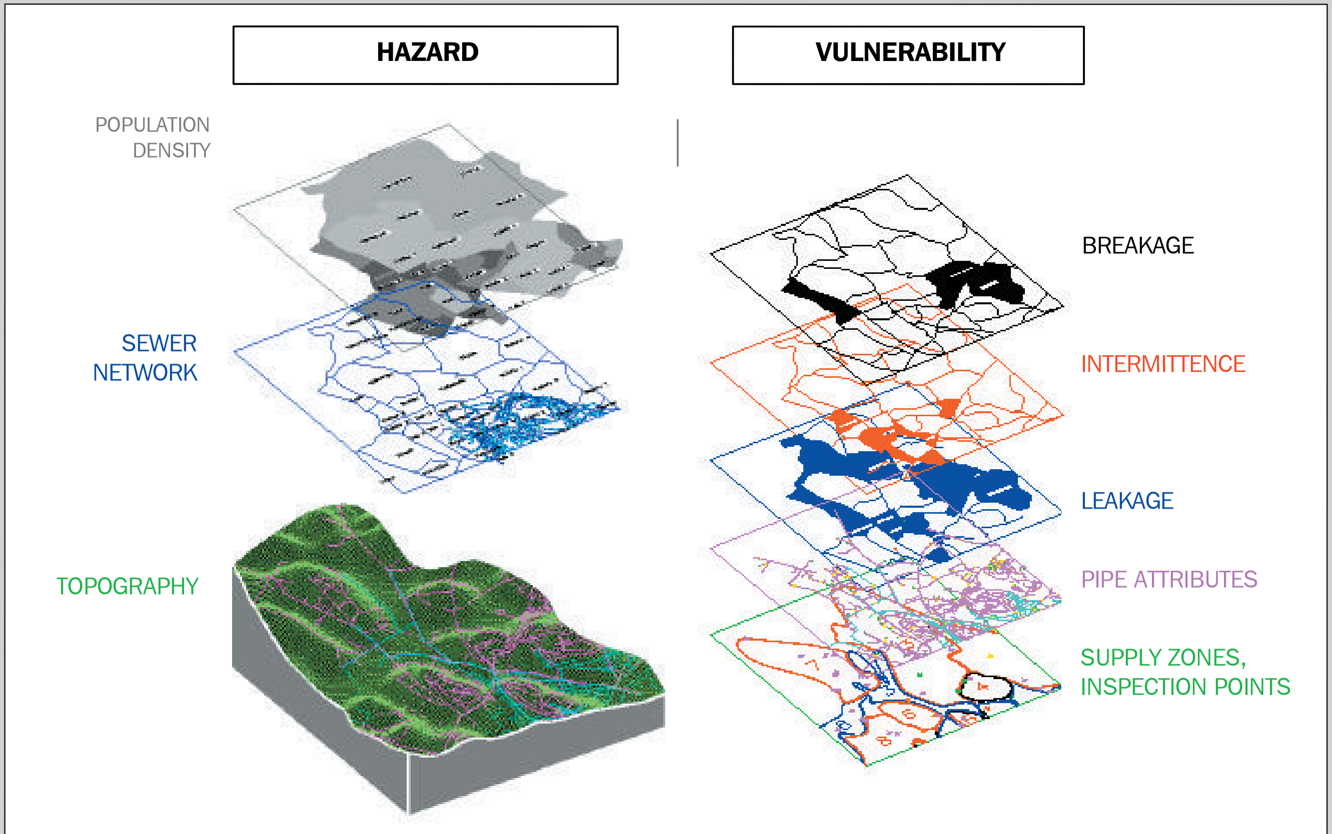
The system comprises of primary and secondary distribution mains (marked as blue and yellow on the map). The primary transmission main begins at the water treatment works and feeds two service reservoirs and one supply tank. The principal secondary mains are marked as yellow. The green and red lines demark supply zones within the network.

Box A3.3. Qualitative identification of risk points

Tracing paper overlays were used to superimpose hazards (indicated as green and purple) and pipe vulnerability (indicated as blue). Inspection points (marked as red and green) were then identified.

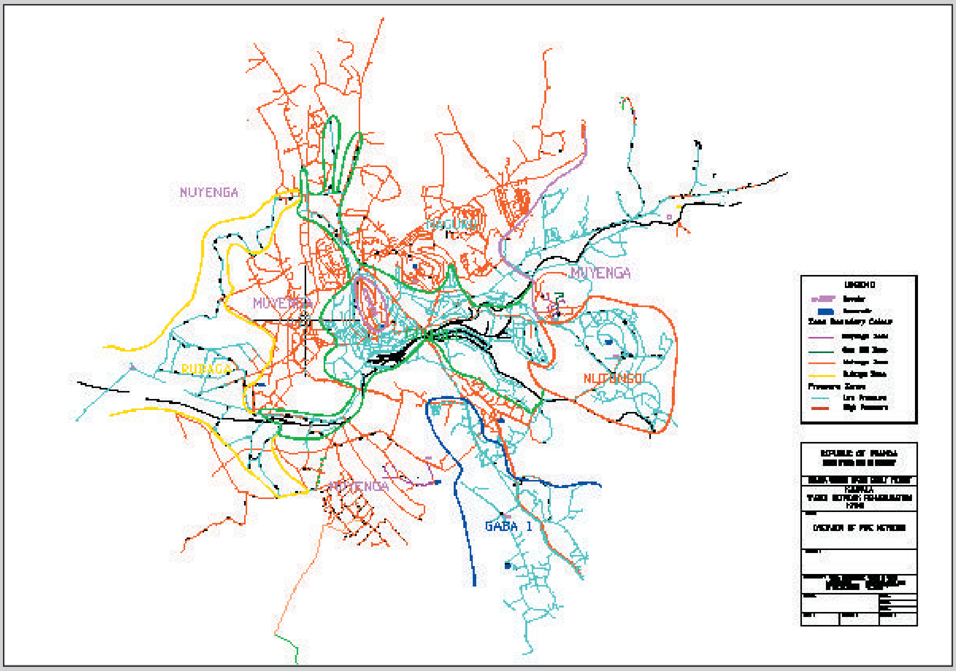


Box A3.4. Layering of quantitative risk maps



Box A3.5. Zoning - Kampala, Uganda

Using expert judgement and available data, the Water Safety Plan (WSP) steering committee in collaboration with the system operator identified the specific hydraulic supply zones for the Kampala distribution network. These zones were identified based on local knowledge of flow patterns within the network, location of service reservoirs and positioning of permanently closed cut off valves. This information was digitized as a layer in the model. With in the Kampala distribution system, 6 major zones were identified with a total of 22 sub zones.

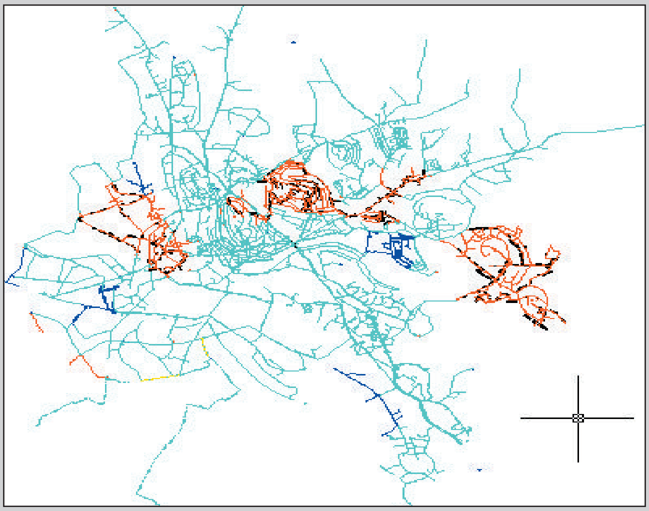


The map indicates 6 supply zones that are demarcated by blue, red, green, yellow and purple lines. Each of these lines is drawn to indicate supply zones that are isolated from one another by cut off valves.

Box A3.6. Semi-quantitative risk estimates

This example outlines the process of undertaking a semi-quantitative risk estimate of the Kampala distribution network. The network comprises of 860km of pipeline and serves approximately 200,000 people. Data on the physical pipe attributes (vulnerability) and historical sanitary risk data (operational data) were obtained from both the system operator OSUL and Kampala City Council (KCC). For pipe vulnerability, data compiled and maintained by OSUL was used, comprising length, diameter, material and age of each pipe section. For operational failure historical records of leakage, breakage and supply intermittence were used.

Data for each of the inspection points was used to define the static vulnerability for that particular section of the Kampala network. This included the use of physical attributes of the related pipe sections (length, diameter, material, age) as well as sanitary risk data (history of leakage, breakage and supply intermittence). This vulnerability score was then combined with data on hazard environment and hazard source to comprise an additive risk score for each inspection point. These scores were plotted as point data onto the GIS platfor



Each were plotted on individual layers with risk scores for individual points within the network being assigned to pipe numbers. Outlet nodes surrounding the point were then identified and through the process of vectorization estimated distances for risk values were computed on to the GIS platform. This data was compiled by on-screen measurement of pipe lengths from Universal Transverse Mercator (UTM) digital blockmaps covering the supply area, the other attributes being derived from as-built documentation. From this, high risk points were selected to be assessed in the field.