Effective Approaches to Water Supply Surveillance in Urban areas of Developing Countries

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Abstract

Ensuring access to safe and adequate water supplies is a key international objective. To meet this goal, information collection and interpretation is essential to guide effective management decisions. The development of health-related oversight of water supply is widely accepted as important in this process. This thesis describes the development and testing of a methodology for surveillance in urban areas of developing countries based on research in Uganda.

The programme of study defined several requirements for surveillance programmes. Assigning the health sector as lead agency for surveillance ensures that data collected are relevant to assessing water-related health risks. Decentralisation of surveillance is an effective approach for acquiring data and developing intervention strategies at local levels.

Surveillance activities should be targeted at those communities that are most vulnerable to water-related health risks. The identification of vulnerable communities can be achieved through the use of a multi-criteria zoning methodology which incorporates a quantitative measure of relative poverty.

A set of robust, quantifiable indicators of water supply is identified for which data can be acquired. These include water quality, water source availability, water source use, costs of water at the household level, discontinuity in supply, qualitative estimates of leakage and quantity of water collected based on level of service.

Appropriate statistical analysis significantly benefits the interpretation of water surveillance data. The use of well-formulated studies is of particular value. The analysis of water quality and sanitary inspection aid understanding of the processes causing contamination and to identify interventions that lead to the greatest improvements. Studies of water usage in low-income communities are important to develop monitoring programmes and intervention strategies.

In conclusion, the application of this methodology is effective in providing
information that assists improvement of water supply. This includes support to improvements in supply operation and design, hygiene education and water supply policy.
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Chapter One

Background and literature review

1.1 Purpose of the study and structure of the thesis

The purpose of this study was to develop a model of water supply surveillance for urban areas of developing countries that provides reliable assessment of water supplies, with particular emphasis on the urban poor. In addition, the study investigated how surveillance information may be used to develop appropriate management actions to improve water supply and hygiene amongst poor urban communities. The study draws on field work in Uganda undertaken between 1997 and 2000 and on the author's wider experience of water supply monitoring and provision in developing countries.

This thesis is divided into eight chapters. The first chapter provides an overview of the key issues that relate to the provision of water supplies in urban areas, the nature of urban growth and urban poverty in developing countries. The introduction reviews current constraints in delivering water services and how poverty can be incorporated into surveillance programmes. The chapter also outlines the influences of water on
health as an important first stage in defining the scope of surveillance programmes and then reviews the evidence for both the need for and previous experience in surveillance programmes in urban areas of developing countries. Chapter 1 concludes with the aims and objectives for the study.

Chapter 2 provides a systematic review of indicators of water supply adequacy that are available for use in surveillance programmes. The indicators of greatest potential value are identified and the means by which data can be collected are reviewed. The indicators tested in field studies in Uganda are identified. Chapter 3 provides details of how field data were collected in Uganda leading to the presentation of results in Chapter 4 (programme development, socio-economic status and urban zoning), 5 (water quality and sanitary inspection) and 6 (other indicators of water supply). Chapter 7 discusses these results in relation to the performance of the field studies in Uganda and the value of the indicators for surveillance programmes in urban areas of developing countries. Chapter 8 presents the conclusion of this work and identifies potential areas of future research.

1.2 Introduction

The provision of basic services, including water supplies, is a major goal in human and social development (WHO, 1999; World Bank, 2001). In the absence of basic services aimed at providing healthy physical and social environments, a large proportion of the world’s population continue to suffer from poor health and socio-economic disadvantage (UNDP, 1999). There are significant links between basic services, health and poverty (World Bank, 2001). The poor enjoy least access to basic services and as a result carry a larger health burden (Stephens et al., 1997). Deteriorating health often leads to reduced incomes or security of income, resulting in reduced capacity to pay for basic services that are available, which in turn leads to further deterioration in health. In relation to water supply, Fass (1993) suggests that the ongoing lack of access to services can lead rapidly into a cycle of deteriorating health and increasing poverty, which may ultimately lead to destitution and may shorten life expectancy.
The alleviation of poverty remains critical to improving the health and well-being of large segments of the World’s population and the provision of basic services is part of this process. Not only are large numbers of the World’s poorest people found in developing countries, but they often live in societies that are highly unequal in terms of distribution of resources and access to services (UNDP, 1999). Addressing poverty often entails addressing inequality in access to services and health differentials, and these may be factors causing ongoing poverty. The improvement in the provision of basic services and the reduction of poverty remain important goals for the international community as articulated by the United Nations Millennium Declaration, which included a set of targets on a range of key social and economic criteria (UN, 2000).

The basic services referred to include the provision of water for domestic purposes. Water is essential for human existence and has well-documented impacts on human health (Ford, 1999). Therefore, the provision of water supplies is an important component of human development (UNDP, 1999).

It has been suggested that one of the key inhibiting factors in addressing poor access to water supplies is that programmes designed to improve services have often not benefited the poor (Briscoe, 1996; World Bank, 1993). Furthermore, investment has often been skewed towards the provision of new infrastructure rather than the sustained operation of existing infrastructure (DFID, 2001a). This leads to limited gains in overall performance as new infrastructure rapidly deteriorates. Even where investment in new infrastructure is warranted, in urban areas this has too often focused on expensive solutions for the few, rather than incremental improvements for the many (Kalbermatten and Middleton, 1999).

The collection of data through monitoring and assessment provides a valuable mechanism through which to provide information that supports more rational priority setting and which can direct investment into areas of greatest gain (Adriaanse, 1997). Such information provides planners with a more reliable basis for selecting investments and targeting resources. To achieve this, monitoring and assessment should address not only those aspects that lead to benefits in a particular area (for
instance incremental health gain), but also whether certain groups or communities continue to be marginalised or lack basic services. Within such an approach, there is a need for both operational forms of monitoring by the suppliers or planners of services and for oversight by an independent body to represent the public interest and promote improvements to those in greatest need.

The development of water supply surveillance programmes in urban areas of developing countries remains limited. There is little evidence in the literature of surveillance programmes that address whole cities or all urban centres in a country, although some studies have been documented that have focused on particular parts of towns, primarily from Latin America (Howard, 1997a; Lloyd et al., 1991). This lack of surveillance development has been noted as a problem. For instance, Thompson (2001) concluded that the development of water quality surveillance and control programmes in Southeast Asian countries was weak and particularly so in poorer countries in the region. Due to these problems, the development of appropriate models of surveillance in urban areas of low-income countries has emerged as an increasing priority (WHO, 1995).

1.2.1 The importance of water supply

The provision of water supply for drinking and other domestic uses is recognised as being essential for improving public health (WHO, 1999). Improved access to good water supplies did much to reduce disease in Western Europe and North America at the end of the 19th and early part of the 20th Century and was credited with reducing epidemics of cholera and typhoid that had previously occurred on a regular basis (Hardy, 1984).

Current rates of access to basic services are low in many developing countries (WHO and UNICEF, 2000). Although the majority of the unserved population is rural, the rapidly increasing urban populations means that many urban households in developing countries are also left with little access to reliable water supplies that deliver good quality water (WHO and UNICEF, 2000). The rate of urban growth, which greatly outstrips that in rural areas, suggests that water supply improvements are urgently needed in urban areas (Black, 1995).
The link between the provision of safe and adequate water supplies and socio-economic growth is important. Access to adequate domestic water is a key component of the human poverty index calculated for developing countries by the United Nations (UNDP, 1999). There remains an international commitment to improving water supply, as illustrated by a resolution in the United Nations Millennium Declaration to halve the number of people that are unable to reach or afford a safe water supply by 2015 (UN, 2000).

In many countries, infrastructure fails to meet the needs of large, growing and predominantly poor urban populations (UNCHS, 1996). Within urban areas, there is significant inequality in access to basic services and research in developing countries has shown this to be linked to significant health differentials (Stephens, 1996). The limited access to adequate and reliable water supply is also suggested as being an important factor in continued poverty in towns and cities of low income countries (Fass, 1993).

Although many problems are understood at a global level, information about the adequacy of water supplies and the health risks faced by urban populations at national or sub-national levels remains scarce in many countries. The lack of independently collected data on water supply inhibits the development of more rational and targeted approaches to water supply and hygiene in many countries. The independent routine surveillance of drinking water supplies is recognised as being an important activity within the water and health sectors and is usually justified because water is known to exert a significant influence on the spread of disease (Ford, 1999; WHO, 1993).

The development of the independent oversight function - or surveillance - in relation to water supply is the subject of this thesis. The work will address the needs for such a process and evaluate a model for improving effectiveness of surveillance in urban areas of developing countries. The thesis is primarily based on work carried out in Uganda, East Africa between 1997 and 2000, but also draws on the author's experience in other developing countries.
1.3 Urban growth and urbanisation

There is little international agreement about what constitutes an 'urban' area and countries use their own definitions based on national population distributions, which makes comparisons between countries problematic (Hardoy and Satterthwaite, 1986; Tacoli, 1998). Whilst definitions of urban and rural areas are largely based on the size of a population residing within a settlement, the classification of populations into 'urban' and 'rural' categories is somewhat arbitrary and may not reflect economic activity (Tacoli, 1998). Yet the classification of settlements may have far-reaching implications in terms of administrative arrangements, allocation of resources, ability to raise tax revenues, nature of income and livelihoods and modes of service delivery (Hardoy and Satterthwaite, 1989). Within this study, urban areas are those settlements classified as such under the prevailing national legislation, which is in line with other work in urban areas (Gilbert and Gugler, 1992; Hardoy and Satterthwaite, 1989).

Urbanisation refers to the process by which an increasing proportion of the population of a country resides in urban areas (Hardoy and Satterthwaite, 1989). The rate of urban growth and urbanisation are important characteristics of human settlement in the late 20th and early 21st Centuries. The rate of urban growth is increasing, with much of the growth occurring in developing or low to middle income countries. The World's urban population increased from 737 million in 1950, to 2603 million in 1995, with the proportion of the population residing in urban areas increasing from 29% to 45% (Flood, 1997). In the year 2000, 2845 million people lived in urban settlements, equivalent to 47% of the global population (UNCHS, 2001). Global urban population growth is higher than in rural areas. UNCHS (2001) estimate that global urban growth rates between 2000 and 2015 will be 3% per annum compared to 0.3% in rural areas in the same period. UNCHS (2001) estimates that by 2015, 53.4% of the World's population will be urban, representing some 3817 million people.

The more industrialised regions of Europe and North America have been predominantly urban in nature for well over 200 years. Much of the less industrialised world has moved on the path of an increasingly urban society only relatively recently and some regions still retain a predominantly rural population (UNCHS, 1996; UNCHS, 2001).
UNDP, 1999). Estimates of the population of the year 2000 suggest that urban populations in countries termed ‘less developed’ by the United Nations Centre for Human Settlements represented 40% of their populations and will not exceed 50% for at least another 15 to 20 years (UNHCS, 2001). However, in countries with lower urban populations, the rate of urban population growth is typically much higher than rural population growth (UNCHS, 2001).

DFID (2001b) note that the degree of urbanisation is related to the overall economic development of nations as goods and services are more readily provided and that urbanisation should generally be positive in terms of economic growth. Gilbert and Gugler (1992) note that it is often perceived that urban areas become the source of economic growth and prosperity and may provide significant improvements in the health and well-being of the urban residents.

Gilbert and Gugler (1992) suggest that although there may be overall economic growth at national levels, the great inequalities within many societies mean that this growth may not benefit the whole population and may lead to increasing gaps between rich and poor. Furthermore, where such inequalities exist, urban and economic growth do not always translate into improvements in health and well-being (Woodward et al, 2000). Mitlin et al. (1996) suggest that in much of the developing world both poverty and health have deteriorated more rapidly in parts of the urban population in comparison to the rural population. The degree to which such deterioration is a short term phenomenon or long-term problem remains uncertain for many countries (Gilbert and Gugler, 1992; Hardoy and Satterthwaite, 1986).

1.3.1 Urban growth in developing countries

Gilbert and Gugler (1992) show that Latin American countries have had predominantly urban societies since the middle of the 20th Century. By contrast, Asia and Africa have generally lagged much further behind and in both continents the majority of the population lives in rural areas, although this varies between countries (World Resources Institute, 1996). Africa remains the least urbanised of any of the continents and in 1997 the urban population stood at 32.4%, compared to a world average of 46.1% and an average for industrialised countries of 77.8% (UNDP, 1999).
It is interesting to note that whilst both Africa and Asia may currently have smaller urban populations, they both have a long tradition of flourishing urban centres. In many parts of Africa, powerful urban centres based on trade and political dominance existed well before colonisation, although they were different in nature to the cities of Europe at the time (Gilbert and Gugler, 1992; Pakenham, 1992).

As noted above, the rate of urban growth in Africa is higher than in regions already largely urban and by 2025 it is expected that the majority of African countries will be over 50% urban (World Resources Institute, 1996). Table 1.1 below provides an indication of growth in Africa compared to other regions. Eastern Africa has traditionally been the least urbanised region within the African continent but now shows accelerating urban growth (Obudho and Mhlanga, 1988).

<table>
<thead>
<tr>
<th>Region</th>
<th>Percent urban population (1995)</th>
<th>Growth rate (1990-95)</th>
<th>Expected percent urban population (2025)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Africa</td>
<td>34</td>
<td>4.4</td>
<td>54</td>
</tr>
<tr>
<td>Asia</td>
<td>35</td>
<td>3.3</td>
<td>55</td>
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<tr>
<td>Europe</td>
<td>74</td>
<td>0.6</td>
<td>83</td>
</tr>
<tr>
<td>North and Central America</td>
<td>68</td>
<td>1.8</td>
<td>79</td>
</tr>
<tr>
<td>South America</td>
<td>78</td>
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<td>Oceania</td>
<td>70</td>
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<td>75</td>
</tr>
<tr>
<td>Global</td>
<td>45</td>
<td>2.5</td>
<td>61</td>
</tr>
</tbody>
</table>

Table 1.1 Urban populations and urban growth (World Resources Institute, 1996)

The growth of urban populations may occur through two, often complementary, processes: natural increase due to high fertility rates; and, rural-urban migration (McMichael, 2000). These processes often interact as migration leads to increasing numbers of urban residents, which leads to greater natural increase in the urban population. This may be further enhanced where migrants are young, leading to an overall younger urban population in comparison to its rural counterparts and hence greater fertility. Both processes will not only contribute to urban growth, but also
increasing urbanisation. The current rates of urban population growth in Africa appears to have been largely driven by rural-urban migration rather than natural increase (Choguill, 1994).

Rural-urban migration in most parts of the developing world is driven by economic factors – both the belief that better incomes can be obtained in urban areas and because of rural deprivation (Hardoy and Satterthwaite, 1986). Movements of population tend to vary over time and from town to town. There is growing evidence that greater rates of growth in urban areas of most African and Asian countries are occurring in small and intermediate towns (UNCHS, 1996). These towns are often viewed as acting as an intermediate step in the process of rural-urban migration (Grant, 1995; McIlwaine, 1997). Movement within and between different urban centres is also recognised as being important (Choguill, 1994; Grant, 1995).

The degree to which migration to urban areas is perceived as permanent may vary, which has significant implications for the investment migrants are willing to make in urban infrastructure. Andreasen (1996) suggests that for many African migrants, the move to the urban area is seen as temporary and that this, combined with a lack of ownership of urban land, leads to a reluctance to invest in expensive urban services. Andreasen further suggests that as capital is accumulated it is more likely to be spent in the home rural area than in the ‘temporary’ urban home, a phenomenon that may persist in second generation urban migrants. The rate of urbanisation may also influence perceptions of permanency of migration, with populations having lower rates of urbanisation likely to have more stable urban populations (Hardoy and Satterthwaite, 1989).

1.4 Urban poverty

Lipton (1977) suggested that the economic potential and political power usually vested in urban areas leads to a significant advantage for urban populations and an ‘urban bias’ in development policies and investment in lower-income countries. Thus, urban areas are viewed as containing populations significantly wealthier than their rural counterparts and current estimates of human poverty tend to emphasise the rural nature of much of this poverty (UNDP, 1999).
However, this view of urban prosperity is being increasingly challenged. Research in developing countries has illustrated the extent, nature and depth of urban poverty (Hardoy et al., 1992; Satterthwaite, 1997; Wratten, 1995). The number of people living in poverty in urban areas is growing much more quickly than in rural areas and the urban poor will constitute over half of the poorest people by the year 2000 (Wratten, 1995).

Satterthwaite (1995; 1997) argues that Governments in developing countries often appear to underplay urban deprivation, which makes true estimates of urban poverty difficult and that official estimates of the number of people living in poverty have been noted to be greatly at odds with experience from the field. This is in part because the standard measure of poverty - 'poverty lines' - are set unrealistically low in comparison with the true cost of purchasing goods and services (including domestic water supply) that may represent a significant proportion of expenditure in urban areas (Satterthwaite, 1997).

Poverty lines are arbitrary levels of per capita income below which households are deemed to lack sufficient income to meet predefined needs. Measures of absolute poverty are commonly used and the World Bank classifies households with a per capita income of below US$ 370 per year (or below US$1 per day) as living in absolute poverty (World Bank, 2000).

Several authors have criticised the use of poverty lines because the levels are often low in comparison to costs of living and because they place too great an emphasis on income, rather than viewing poverty as a complex set of social and economic relationships (Moser, 1995; Rakodi, 1995; Wratten, 1995). These workers suggest that poverty depends on many factors that influence the ability of a household to access goods and services and their ability to fully participate in the society. Income is often difficult to precisely gauge and security of income may be at least as important as the value of the income in obtaining services (Satterthwaite, 1997). Furthermore, the means by which households obtain basic goods and services are often complex and not necessarily heavily reliant on the cash economy (Moser, 1995; Rakodi, 1995; Wratten, 1995).
One of the principal problems with sole reliance on wage income in defining poverty is that this may not represent the most significant source of livelihood (Moser, 1995; Rakodi, 1995; Wratten, 1995). Satterthwaite (1997) notes that wage income may not be the major factor in determining whether access to basic services – water supply, sanitation, access to health services, education – can be assured. For instance, Bigsten and Kayizzi-Mugerwa (1992) showed that in 1990, wage incomes accounted on average for only 17% of total household income in Kampala, Uganda, although it was estimated that 72% of households had at least one wage income. Income from business was more important both in terms of proportion of total income (47%) and in numbers of households. Allowances also made up a significant proportion of total income (27%) for over 50% of the households. Birley and Lock (1998) and Tacoli (1998) note that although urban families spend a far higher proportion of their income on food than rural families, many urban families also engage in agriculture, which reduces the proportion of income that must be spent on food.

It is increasingly recognised that one of the greatest problems facing poor households is their vulnerability to economic shock, which may reduce their financial risk-taking (Bigsten and Kayizzi-Mugerwa, 1992; Chambers, 1989). Howard (2001) notes that one consequence of reduced risk-taking by poor households may be avoidance of water supplies that have a risk of long-term debt, such as those provided by utilities that issue bills on a relatively infrequent basis.

The above arguments suggest that in order to address poverty in urban areas, it is more appropriate to assess the social as well as economic facets of household life (Rakodi, 1995; Satterthwaite, 1997). Such measures may include housing quality and access to services. When assessing such measures, it becomes increasingly clear that a very large proportion of the urban populations in developing countries are extremely poor and suffer from poor health as a consequence (Satterthwaite, 1997; Stephens et al., 1997).

1.4.1 The relationships between poverty, health and access to services

The health of households and communities is closely linked with socio-economic conditions (Stephens and Harpham 1992; Todd, 1996). The health problems
associated with urbanisation led a WHO Commission in the early 1990s to conclude that: ‘The crisis in the urban environment is producing more immediate effects on health than would be expected from the current changes in the natural environment’ (WHO, 1992). This same Commission went on to state that ‘For hundreds of millions of people, the urban environment is already destroying lives, health and social values, and, in most cities, is contributing to illnesses, accidents and crimes’.

Although there is a lack of published data on the relative health burdens of the rural and urban poor, some researchers suggest that the health of poor urban communities is frequently more greatly compromised than their rural counterparts, as they live in more crowded and polluted environments (Andreasen, 1996; Howard, 1996). Women and children in particular suffer increasing health burdens, often because their needs and roles are not adequately addressed in programmes designed to alleviate the effects of urban poverty (Chant, 1998; Kettel, 1996). A significant proportion of the health disadvantage of the urban poor is caused by the limited access to adequate housing and basic services, in particular water supply and sanitation (Satterthwaite, 1995; Satterthwaite, 1997; Stephens et al., 1997).

Differentials in health within cities (including quality of life, disease burdens and life expectancy) have been widely reported (Brockerhoff, 1995; Oni, 1988; Singh et al., 1996; Stephens et al., 1997; Wang’ombe, 1995; ). Work by Obudho and Mhlanga, (1988) and Stephens (1996) suggests that urban areas in developing countries frequently contain a small elite who have lifestyles similar to those of the wealthy in developed countries. These groups are surrounded by the majority of the population that is poor and whose health is severely compromised.

The health of migrants to cities appears to be disadvantaged in comparison with natives of urban areas. In a study of data from Demographic Health Surveys in the 1990s, Brockerhoff (1995) observed that child survival amongst migrant families was significantly worse than those of urban natives and was worst amongst migrants who had lived in the urban area for at least 10 years. Brockerhoff also concluded that migrants to big cities were worse off than migrants to small and intermediate towns.
In addition to direct health risks associated with poor access to services, the poor face a further health disadvantage as their settlements are frequently built on marginal land prone to disasters which often have immediate and devastating effects on the health of the population (Main and Williams, 1994).

The patterns of use of basic services by wealthier groups may also influence the ability of the urban poor to access basic services. For instance work in both Ghana and Brazil illustrated that the inability of the poor to gain access to adequate water supply was a direct consequence of the consumption patterns of the rich in areas where there are significant constraints in availability of source waters (Stephens, 1996; Stephens et al., 1997).

The above arguments suggest that poor households and communities in urban areas often have limited access to basic services and greater vulnerability to disease than other urban groups. This suggests that any process designed to monitor water supplies should incorporate some measure of poverty when assessing whether the urban poor suffer particular disadvantage. Howard and Luyima (1999) and Lloyd et al., 1991) indicate that the urban poor should be viewed as a group of particular importance for surveillance programmes.

1.4.2 Urban settlements and their implication for water supply provision

The rapid increase in urban growth noted for many developing countries, has a profound influence on the capacity of Governments and utilities to provide water supplies of the types now found in the industrialised world, which themselves often took many years to develop (Black, 1995). The paradigm of service provision has also seen a significant change, with cost-recovery from individual consumers and demand-driven approaches being explicit objectives in developing countries (World Bank, 1993). This demonstrates a significant departure from the approach in the Victorian ‘sanitary revolution’, which considered the provision of water and sanitation services as essential public works designed to improve public health, and often with secondary and broader social and economic objectives (Melosi, 2000).
As the preceding section demonstrates, within this new paradigm the delivery of services is hampered by the fact that so many of the new population are poor and furthermore the poor may have limited incentives to purchase services. This may be due to the cost of the services, which often appear relatively high in both capital investment and ongoing tariffs. Andreasen (1996) and Satterthwaite (1997) note that many of the urban poor are tenants and this may lead to a reluctance to invest in water services, as a principal outcome may be an increase in rent. As a result, the poor population tends to reside in areas that rapidly deteriorate into ‘slums’ - over-crowded settlements with few or no services and residents with low incomes living in highly polluted environments. Some infrastructure may be available in these areas, although it is often of a very basic nature and may include a variety of formal and informal water supplies (Ahmed and Hossain, 1997; Gelinas et al., 1996; Howard, 2001; Rahman et al., 1997; Rojas et al., 1995).

Huq-Hussain (1996) suggests that new migrants tend to settle in areas close to the centre of towns and cities, which rapidly develop into the classical vision of a slum described above. However, not all slums are recent developments and many in African towns have a long history of existence (Obudho and Mhlanga, 1988). Slums may be legal settlements that have deteriorated or never been improved, or informal (sometimes called illegal) settlements. In some cases the age of informal settlements has conferred a de facto legal status even if no de jure recognition has been conferred (Gilbert and Gugler, 1992). These settlements are referred to here as being ‘semi-legal’.

There are often technical constraints in providing tertiary infrastructure to deliver services to individual households in legal or semi-legal slums in the centre of urban settlements. This may not be capital-intensive as primary and secondary infrastructure often exists either close to or sometimes within the settlement (WELL, 1998). As a result, services can often be improved at relatively low cost provided there is local support. Briscoe (1996) cites the example of the Orangi Pilot Project in Karachi, Pakistan, as an example of how basic services (in this case sewerage) can be provided in high-density, low-income settlements where there is active participation of communities in planning and implementation and appropriate technology is used. In
this project, the residents in a slum area planned, constructed and built a modified sewerage system that eventually was linked to the main urban sewer system (Howard and Bartram, 1993). Briscoe (1996) notes that the Orangi Pilot Project proved to be a sustainable improvement in sanitation in an area that had previously had very poor sanitation.

In addition to legal or semi-legal slums, the increase in urban growth and in-migration has also resulted in the development of newer ‘squatter’ settlements, which are generally viewed as informal or illegal settlements (Hardoy and Satterthwaite, 1989). Squatter settlements often involve direct invasion of land either not utilised or under-utilised. Hardoy and Satterthwaite (1989) note that in these areas the housing stock is often much more recent and a much larger proportion of the population own their house, if not the land on which it stands. Cairncross (1990a) noted that typically such areas have no available infrastructure and frequently such land is also prone to significant environment problems such as landslides or flooding. WELL (1998) notes that service provision to squatter settlements may require capital intensive investment.

Payne (1997) shows that the nature of tenure in squatter settlements varies significantly and reflects the complexity of land laws in many developing countries, particularly Africa, where customary, commercial and public forms of tenure exist. Payne (1997) further notes that some invaded land has a degree of legitimacy in that its development has been sanctioned through customary law. Other reviews note that more commonly there is no legal sanction of any kind for the settlement and the lack of a formal legal title to the land may act as a significant barrier to any form of service provision (Andreasen, 1996). As a result, other forms of water supply are developed such as protected springs, boreholes and dug wells (Ahmed and Hossain, 1997; Gelinas et al., 1996; Rahman et al., 1997; Rojas et al., 1995). In these cases the water supply is often acceptable to the users, as it is a technology that is familiar from home rural areas and represents a limited financial burden to the users (Andreasen, 1996).

The legal status of such settlements may change over time, although this seems to vary regionally. For example in Latin America, many squatter settlements have achieved legal status fairly rapidly (Hardoy and Satterthwaite, 1989). Hardoy and
Satterthwaite (1989) suggest that because these settlements often contain a significant number of owner-occupiers, there is an increased level of willingness to pay for services. The situation in Africa is often different, as the populations residing in invaded areas are more likely to be tenants renting from absentee landlords and as a result there is limited incentive to provide or purchase services (Andreasen 1996). A recent study also noted that in Uganda, many residents of informal settlements rent from ‘secondary’ landlords, who have themselves illegally occupied land and built houses to rent to other low-income families (Aquaconsult, 2002). This study noted that the true owner of land may not wish to see services provided to the current residents or indeed lobby to ensure that these are not provided.

In addition to the development of slums and squatter settlements are villages that become incorporated into cities as urban growth continues. These would usually have a legal status (Obudho and Mhlanga, 1988). Howard (2001) notes that these settlements are often well-established, but whose current forms of water supply are often of lower quality than those found elsewhere within urban areas. Howard (2001) suggests that because these are relatively stable communities, water supply improvement is often easier as willingness to pay may be more easily secured, but that provision may require capital intensive investment to ensure that services can be delivered.

The discussion above shows that water supply provision to the poor is hampered by several problems, including legality of tenure, nature of occupancy and willingness to pay. In addition, it may result from simple inability of service providers to plan and deliver services in a manner and a rate that keeps up with population growth and are appropriate to the needs and demands of the population (Wall, 1997).

1.4.2.1 The approaches developed by the water sector to deliver services

In a review of the problems in achieving greater access to water supplies in developing countries, the World Bank (1993) identifies the inefficiencies of water supply provision by Governments as being a major cause of service provision failure. The World Bank (1993) argues that these have failed to place an adequate value on
water supplies and cost-recovery and as a result many water supplies have failed to be sustained beyond short working lifespans.

Furthermore there is also a recognition that too little attention has been paid to the participation of end-users in the development of water services that meet their needs and willingness to pay (WELL, 1998). Various authors note that in urban areas of developing countries, the prime beneficiaries of subsidised water supplies have been the wealthier households and not the poor, who pay far higher costs for alternative, and usually worse, services (Briscoe, 1996; Cairncross and Kinnear, 1992; Nixon, 1997; Whittington et al., 1991). In a guidance manual for water and sanitation provision, WELL (1998) notes that the emphasis in the water sector is to avoid using subsidies where users were willing and able to pay for services and limit subsidies to those groups that are unable to meet the costs of such services. It is also suggested that subsidies should be provided directly to households and not the water supplier (WELL, 1998).

Increasingly, the role of the private sector in delivering improved services is promoted, as it often has greater access to capital for investment and is perceived to be more efficient in service provision and have a greater ability to recover costs from end-users (Jones, 1997). Private sector arrangements vary widely throughout the world, but only in the UK was the full sale of assets to the private sector carried out. Elsewhere the arrangements have tended to follow the ‘French’ model more closely, with a variety of concession, lease and management contracts made between public and private sector agencies (Jones, 1997).

The evidence that private sector provision of water supply results in better services for the poor remains scanty (Bailey, 1996). Briscoe (1996) and Sharma et al. (1996) provide examples that generally support the effectiveness of private sector delivery of water supply services, although it should be noted that much of this derives from the World Bank who actively promote private sector participation. By contrast, Bailey (1996) provides evidence that public utilities can be more efficient service providers than the private sector. Some workers have concluded that provided water suppliers
follow good management practices, either the private or public sectors can be effective service providers (Cairncross, 1990a; Nixon, 1997).

Several authors (Cairncross, 1990a; Cottam; 1997; Howard, 2001) have noted that a problem in many developing countries is that service providers and planners view the urban poor as a homogenous group for whom single or very restricted options exist for improvement of services. In a review of experience of water supply provision in developing countries, Kalbermatten and Middleton (1999) note that a lack of involvement by end-users often promotes unrealistically high levels of service that are difficult for households to purchase and sustain. There is increasing recognition that more flexible approaches to water supply provision for urban populations are required (Sansom et al., 2000; World Bank, 1993).

Several authors suggest that greater direct involvement of end-users would be more likely to result in services that are sustainable, as the service would reflect more closely the actual demands of the user population (Briscoe, 1996; Kalbermatten and Middleton, 1999; WELL, 1998). Research by several groups suggests that low-income urban communities can take a more active role in the management of water supplies and has included:

- bulk purchase of water from a utility with subsequent management of intra-community distribution (McCommon et al., 1998);
- community contract management and procurement of services from the private sector (Cotton and Taylor, 1994);
- establishment of public taps managed by communities (Singha, 1996);
- improvement of point supplies as an intermediate solution (Howard et al., 2001a);
- development of alternative administrative structures in delivery of services through water user associations (Subramanian et al., 1997).

In each case, the authors note that community participation proved effective in improving the sustainability of the improved service and that alternative arrangements offered a viable approach to service delivery. Cairncross (1990a) drew a similar
conclusion and provided an example of how support to vendors in Sudan would be expected to improve many aspects of the water supply used by poor households.

Mitlin and Thompson (1995) point out that in many developing countries there is a long tradition of community-based approaches to development in urban areas. Several authors note that there is evidence that community-based action and collaboration between communities and local Governments can be an effective approach to sustained service delivery (Hardoy and Satterthwaite, 1989; Mitlin and Thompson, 1995; Satterthwaite, 1997).

Concerns have been raised by several workers regarding the viability of community management of water supplies as a long-term solution to service provision, although this typically relates to rural as opposed to urban areas (Feachem, 1980). Indeed, Carter et al. (1993) suggest that community management should only be seen as a medium-term solution to water supply provision. Kalbermatten and Middleton (1999) support this and suggest that in the urban sector, community management should be viewed as an incremental step in improving water supply, which would be expected to be progressively upgraded.

The evidence suggests that the mode of delivery – whether public, private or community-managed – is less important than the implementation of sound financial management of the water sector (Briscoe, 1996; World Bank, 1993). It is apparent that good and bad experience may be found with all forms of water supply management and operation and that the adoption of a particular approach should be determined on a case by case basis in order to reflect local capacity and conditions (Nixon, 1997). The underlying basic principle that costs must be recovered through some sustainable mechanism is important, as otherwise services tend to contract and the poor are those that most rapidly lose access. However, cost-recovery must also take into account the ability of the poor to pay for services and not create disincentives for the use of water supplies. It is also implicit that services must meet the demands of the poor and be flexible enough to encompass a range of demands (Briscoe, 1996).
1.5 The relationship between water supply, sanitation and health

The importance of water to health has been recognised since antiquity, however, the scientific evidence of the impact on human health from drinking-water has been relatively recent. Improvements in water supplies were driven to a large extent by the 'sanitary reformers' of the 19th Century in Europe and North America in response to epidemics of cholera, typhoid and dysentery (Hardy, 1984; LeChevalier and Au, 2001). As noted by Cairncross (1990b), the scientific understanding of the relationship between water and health remained an issue of debate and emerged after improvements had been initiated. The development of the 'sanitary concept' in the UK and elsewhere in Europe and North America during this time remains a starting point for many countries in improving public health (Werna et al., 1998).

Water has a direct effect on health through the consumption of water contaminated by pathogens leading to infectious diarrhoeal diseases, and by toxic chemicals leading to acute and chronic illnesses (WHO, 1993). Water also directly affects infectious disease transmission through the quantity of water available for consumption and basic hygiene (WHO, 1993). Aspects such as poor accessibility, high costs and poor reliability of water supplies, may force households to use water in insufficient quantities to practice good hygiene or resort to alternative, lower quality, sources of water with consequent risks to health (Howard, 2001; WELL, 1998).

The priority concern in relation to health impact of water supply is its role in the transmission of infectious diarrhoeal diseases (WHO, 1993; 1996a). Several authors note that diarrhoeal diseases are of particular importance in developing countries, as they contribute significantly to the high infant mortality and morbidity rates typically associated with poor countries (Ford, 1999; Murray and Lopez, 1993; Okun, 1993). Table 1.2 below provides figures for the ten highest causes of morbidity and mortality for 1999 (WHO, 2000). This shows that globally, diarrhoeal diseases were still the 7th highest cause of mortality and the cause of 5% of the total burden of disease as expressed in Disability Adjusted Life Years (DALYs).
Overall, it is estimated that 5.7% of the global burden of disease can be attributed to poor water, sanitation and hygiene (Prüss et al, 2002). In wealthier countries, recent outbreaks of infectious diseases linked to poor water quality (such as cryptosporidiosis and *E.coli* O157) has re-focused attention on the role of water in spreading such diseases (Okun, 1996). This suggests that monitoring and control of water supply is important to ensure that transmission of pathogens is reduced.

<table>
<thead>
<tr>
<th>Mortality</th>
<th>Morbidity</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Disease</strong></td>
<td><strong>Percent</strong></td>
</tr>
<tr>
<td>Ischaemic heart disease</td>
<td>12.7</td>
</tr>
<tr>
<td>Cerebrovascular disease</td>
<td>9.9</td>
</tr>
<tr>
<td>Acute lower respiratory infection</td>
<td>7.1</td>
</tr>
<tr>
<td>HIV/AIDS</td>
<td>4.8</td>
</tr>
<tr>
<td>Chronic obstructive pulmonary disease</td>
<td>4.8</td>
</tr>
<tr>
<td>Perinatal conditions</td>
<td>4.2</td>
</tr>
<tr>
<td>Diarrhoeal diseases</td>
<td>4.0</td>
</tr>
<tr>
<td>Tuberculosis</td>
<td>3.0</td>
</tr>
<tr>
<td>Childhood diseases</td>
<td>2.8</td>
</tr>
<tr>
<td>Road traffic accidents</td>
<td>2.2</td>
</tr>
</tbody>
</table>

Table 1.2 Top ten causes of global mortality and morbidity, 1999 (WHO, 2000)

NB: Morbidity figures in brackets are estimated Disability-Adjusted Life-Years
1.5.1 The importance of different routes of diarrhoeal disease transmission

Infectious diarrhoeal diseases are primarily transmitted through the faecal-oral route, which may occur through a variety of mechanisms, including consumption of water and food as well as through person-person contact (Bradley, 1977). These are shown in figure 1.1 below.

Figure 1.1: Faecal-oral route transmission of disease (taken from WELL, 1998)
The influence of ingestion, hygiene and excreta disposal on the faecal-oral route diseases has led to significant debate over the effectiveness of different interventions (Esrey et al., 1985). This has mirrored a broader debate within the health sector worldwide regarding the need for quantifiable evidence in reducing health burdens (WHO, 2000). The desire for evidence-based health interventions is driven by the need to maximise health gains from limited resources.

As part of the understanding of the debate about the importance of different interventions in reducing diarrhoeal disease, it is of value to consider their classification. Whilst the approach of classifying infectious diseases by microbe type has a value in terms of understanding aetiology of infection, a more effective way to inform decision-making is to categorise pathogens in relation to the broad mode of transmission. Bradley (1977) described four principal categories that relate to water:

- water-borne (caused through consumption of contaminated water);
- water-washed (caused through the use of inadequate volumes for personal hygiene);
- water-based (where an intermediate aquatic host is required); and,
- water-related vector (spread through insect vectors associated with water).

The advantage of such an approach is that it allows health professionals to be able to identify what types of intervention are likely to have the greatest impact on disease transmission and incidence. Of the categories of diseases noted above, water supply directly affects the first three but can only be expected to affect the final category indirectly insofar as improved water supply may reduce the exposure of the population to vectors. Whilst this simple classification has been further refined in relation to specific transmission route for each etiological agent and means of excreta disposal (Cairncross and Feachem, 1993) and in relation to the broader housing environment (Mara and Alabaster, 1995), the original approach remains robust.

The strength of the system described by Bradley (1977) is its focus on causative factors rather than modes of transmission and therefore provides indications of the potential impact of different interventions. The potential overlap of particular diseases
between different groups is an inherent problem in all forms of categorisation that do not deal solely with morphological characteristics of pathogens. For instance, although guinea worm could be classified as a water-based disease, its transmission into humans is via consumption of water.

1.5.1.1 The relationships between water, sanitation and diarrhoeal disease

Whilst numerous studies have been undertaken to investigate the relative importance of different interventions, relatively few have been sufficiently rigorous to allow quantified reductions in disease to be calculated. In a review based on 67 studies, Esrey et al. (1985) investigated the relationships between diarrhoeal disease and a number of factors including water quality, water availability and excreta disposal. The findings from this review are presented below in table 1.3 and suggest that median reductions in diarrhoeal disease arising from improved water availability were higher than those recorded for water quality improvements. Concurrent improvements in both quality and availability led to even greater median reductions in disease incidence. However, it should be noted that the variation in reduction from each intervention type was significant, with the highest recorded reductions ranging from 48% to 100%. For all interventions, studies were reported that led to no measurable reduction in diarrhoeal disease.

<table>
<thead>
<tr>
<th>Type of intervention</th>
<th>Number of studies</th>
<th>Percentage reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Median</td>
</tr>
<tr>
<td>All interventions</td>
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</tr>
<tr>
<td>Improvements in water quality</td>
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<td>16</td>
</tr>
<tr>
<td>Improvements in water availability</td>
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<td>25</td>
</tr>
<tr>
<td>Improvements in water quality &amp; availability</td>
<td>8</td>
<td>37</td>
</tr>
<tr>
<td>Improvements in excreta disposal</td>
<td>10</td>
<td>22</td>
</tr>
</tbody>
</table>

Table 1.3: Percentage reductions in diarrhoeal disease rates attributed to water or excreta disposal improvements (Esrey et al., 1985)

In a subsequent review of 144 studies looking at various different single and multiple interventions in water and sanitation by Esrey et al. (1991), relatively few (56) were
deemed to be rigorous and only 24 could be used to calculate morbidity reductions. The findings from this study are shown in table 1.4 below. The data from the rigorous studies suggested that median reductions in morbidity were relatively low from all water supply improvements, unless these were combined with sanitation improvement. The impact of combined improvements in water quality and quantity resulted in a lower reduction in morbidity than for water quantity interventions alone, which contradicts the findings of the previous review by these authors. Esrey et al. (1991) note that the benefits derived from improved water availability were not necessarily felt in all age groups, a finding highlighted in a previous study by Herbert (1984).

<table>
<thead>
<tr>
<th>Factor</th>
<th>All studies</th>
<th>Rigorous studies</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>% reduction</td>
</tr>
<tr>
<td>Water and sanitation</td>
<td>7</td>
<td>20</td>
</tr>
<tr>
<td>Sanitation</td>
<td>11</td>
<td>22</td>
</tr>
<tr>
<td>Water quality and quantity</td>
<td>22</td>
<td>16</td>
</tr>
<tr>
<td>Water quality</td>
<td>7</td>
<td>17</td>
</tr>
<tr>
<td>Water quantity</td>
<td>7</td>
<td>27</td>
</tr>
<tr>
<td>Hygiene</td>
<td>6</td>
<td>33</td>
</tr>
</tbody>
</table>

Table 1.4: Reductions in diarrhoeal disease morbidity for one or more components of water and sanitation improvement (Esrey et al, 1991)

A variety of different findings have been reported in other studies from developing countries looking at diarrhoeal disease incidence. Esrey (1996) concluded on the basis of a review of data from Demographic Health Surveys from 11 countries that improvements in sanitation led to more significant reductions in diarrhoeal disease than improvements in water supply. Baltazar et al. (1993) found that in the Philippines, increasing risks of hospitalisation due to severe diarrhoea were noted with declining hygiene standards, but only indices of overall cleanliness (a composite measure of environmental hygiene and personal appearance) and kitchen hygiene were significantly associated with diarrhoea. A study in Accra, Ghana, indicated that
risks posed by poor water supply and recontamination during household storage were more important than sanitation and personal hygiene (McGranahan et al., 1997).

Kelley et al. (1997) reporting the result of an investigation of infection with cryptosporidium in Lusaka, Zambia, showed that the most significant relationship with infection was consumption of treated piped water drawn from a surface water source. Incidence of diarrhoea was higher in the group using this water than in groups using water drawn from deep boreholes; the affected group did not have any significantly greater contact with animals nor consumed water from alternative sources.

A study in Cebu in the Philippines suggested that non water-borne transmission routes for diarrhoeal disease would predominate when faecal contamination of domestic water, as indexed by E. coli, was below 1000 cfu/100 ml (Moe et al., 1991).

Much attention has been paid to deterioration in water quality between source and consumption particularly when the source is outside the home (Genthe et al., 1996; Jagals et al., 1997; Pinfold, 1990; WHO, 1993). There have been suggestions therefore that improvement of source water quality is not worthwhile unless this can be maintained up to the point of consumption (Feachem, 1980).

Vanderslice and Briscoe (1993) challenged this view and suggested that source water quality was of greater importance, primarily as pathogens introduced during transport and storage would already circulate within the family and would be transmitted more easily by other routes. In the outcome of studies in the Philippines, it was estimated that moderate improvements in source water quality would lead to reductions of up to 30% in diarrhoeal disease morbidity whereas household water treatment would be associated with little improvement. It was concluded within this study that improvements in health would not be seen as a result of improved source water quality if community hygiene remained poor (Vanderslice and Briscoe, 1995). A more recent study suggested that if E. coli was present in water at above 100 colony forming units per 100 ml, then improvements to source water were more important than promotion of water handling hygiene (Jensen et al., 2002).
In a review of evidence for promotion of household water treatment, Sobsey (2002a) demonstrates that these interventions can deliver very substantial reductions in diarrhoeal disease incidence. Research in Uzbekistan showed that household chlorination of drinking water by households without a connection to the piped water supply at their home resulted in a 62% reduction in diarrhoeal disease incidence compared to a group with a piped water connection, but who did not chlorinate in the home (Semenza et al., 1998). This was despite the poorer sanitary conditions and socio-economic status of the intervention community. The authors demonstrate that even greater reductions (85%) were noted compared to households without a piped water connection to their home and who did not chlorinate their water.

In Bolivia, the introduction of simple storage containers with disinfection, and supported by hygiene education, led to over 44% reduction in diarrhoeal disease incidence in the general population and over 50% reduction in children, despite poor community sanitation (Quick et al., 1999). In a study by Handzel (1998) in Bangladesh, a 25% reduction in diarrhoeal disease was found through improvement in water quality alone in slum areas with poor community hygiene. A recent study in Kampala, Uganda that showed that treatment of water in the home was associated with a decrease in acute diarrhoeal disease (Nasinyama et al., 2000).

In a randomised intervention trial with improved water containers in a refugee camp a 31% reduction in diarrhoea among children under 5 was shown (Roberts et al., 2001). This is supported by previous research that focused on improved hygiene of household water containers in India (Deb et al., 1986).

The evidence from the literature suggests that water availability has an important influence on health and in particular diarrhoea incidence, although as noted by both Esrey et al. (1991) and Herbert (1984) this is not necessarily true for all age groups. Esrey (1996) suggests that it is only when the water supply is delivered on-plot that health gains are found. It is also noted that this may be due to a number of factors, not least of which is the better socio-economic status of households with this level of service and possibly a better quality of water supplied (Esrey, 1996). It is important to
note that there appears to be no published literature on the impact of providing non-piped water supplies on-plot, which would be of particular importance in determining the fraction of diarrhoeal disease that is directly attributable to increased service level and the fraction attributable to other factors.

The impact of water availability may have particular benefits for child health. Prost and Négrel (1989) suggest that the quantity of water used for children’s hygiene is sensitive to availability and that reducing the time taken to collect water (including journey and waiting time) from 5 hours to 15 minutes, results in 30 times more water being used for child hygiene. It is suggested that reducing the time taken to collect water will also allow greater time to be available for child feeding, food preparation or more frequent feeding, as well as better hygiene. Other studies suggest that reductions in diarrhoeal disease with increased service levels may in fact be much more modest (Vanderslice and Briscoe, 1995). Gilman et al. (1993) found a positive relationship between the quantity of water available in the home and the frequency of handwashing in a shantytown and concluded that hygiene education was of limited value unless water supplies were improved.

The relationship between quantities of water and hygiene is not simple and most research has made significant assumptions about water use. Hygiene is not solely related to availability of water, but also to specific hygiene behaviours such as hand washing at critical times, for instance before eating and cooking and after defecation (Cairncross, 1993; Petersen et al., 1998; Shahid et al., 1996; Sircar et al., 1987; Stanton and Clemens, 1987). Factors other than handwashing hygiene may influence the contamination of hands, of which humidity and temperature are reported to be important (Pinfold, 1990).

In relation to hygiene practices, a review by Huttley et al. (1997) suggested that targeting programmes on a single behaviour was more effective than addressing several behaviours when promoting hygiene. They suggest that a median reduction of 35% in diarrhoeal disease morbidity from improved hand-washing is achievable through well-designed hygiene education programmes. The timing of hand-washing is noted as important. Curtis et al. (2000) suggest that the critical time is post-defecation
rather than before eating, while other studies suggest that the reverse is true in some situations (Birmingham et al., 1997). Stanton and Clemens (1987) found that reduction in diarrhoea incidence among young children was influenced by maternal hand washing prior to food preparation. A number of studies suggest that hand-washing with soap is the critical component of this behaviour and that hand-washing only with water provides little or no benefit (Cairncross, 1993; Ghosh et al., 1997; Oo et al., 2000).

Other studies have assessed the impact of different water supply and sanitation interventions using different outcome measures. A study in India that used nutritional status as a health measure suggested that water quality was the principal determinant for health in children under the age of 3, whereas water quantity was most important for children above 3 (Herbert, 1984). A previous study in rural Lesotho showed that height for weight scores were more strongly associated with latrine use than water quantity (Esrey et al., 1992). In this study, water quality was not analysed as it had previously been found to be insignificant. However, in South India, defecation practice was not a significant predictor of height for weight scores (Herbert, 1985).

Other studies point to other factors that are of importance in reducing diarrhoeal disease. In Saudi Arabia, Al-Ali et al. (1997) showed that breast-feeding was particularly important in control of diarrhoeal disease where universal access to treated piped water supply was achieved.

The studies reviewed above relate to endemic diseases. However, influences on transmission for epidemic disease may be different. In the case of epidemic disease, explosive outbreaks tend to occur via single or very restricted numbers of transmission routes and for most of the faecal-oral route diseases, single source media are restricted to food and water (Haas et al., 1999). Whilst food-borne outbreaks undoubtedly account for a significant number of outbreaks, the role of drinking-water supplies as a mechanism for epidemic spread remains important in developed and developing countries (Ford, 1999). These sentiments are mirrored in a report prepared for the American Academy of Microbiology, that ‘a typically large and widely disseminated outbreak may result in many secondary cases not directly related to
contaminated water, but that would not have occurred in its absence' (Ford and Coldwell, 1996).

Drinking-water supplies have been implicated in the spread of infections caused by a range of bacterial, protozoan and viral pathogens. These have included *E. coli* O157 (Clarke et al., 1993a); *Salmonella typhimurium* (Clark et al., 1993b); *Shigella* spp. (Swaddiwudhipong et al., 1995); cholera (Geldreich et al., 1991; Salazar-Lindo, 1993); *Cryptosporidium parvum* (Freidman-Huffman and Rose, 1999); and Hepatitis A and E viruses (Grabow, 1996; Rab et al., 1997).

These outbreaks have resulted directly from consumption of contaminated drinking water and therefore the control of water quality has a particular role in epidemic control irrespective of its importance in reducing endemic disease burdens (Ince and Howard, 1999). Improvements in excreta disposal and access to water supply may have an impact by reducing the conditions favourable to an epidemic outbreak but would not be able to control such epidemics without effective control of drinking water quality (Ford and Coldwell, 1996).

1.5.1.2 The relationships between water supply and other infectious diseases

Water supply adequacy is also important in the control of other infectious diseases linked to hygiene (WHO, 1993). Of these diseases, trachoma is the most extensively studied, given its relatively high impact on health (Prüss et al., 2002). In a review of available evidence, Prüss and Mariotti (2000) found only two studies that showed a significant relationship in terms of quantity and suggested that the relationship between trachoma incidence and quantity of water was not simple. Prüss and Mariotti (2000) review a study in southern Morocco that showed a difference in incidence in trachoma between the use of less 5 litres per day and use of more than 10 litres per day. Another study was noted as indicating no relationship to quantity of water used, but which showed a strong relationship between availability of water and trachoma.

In separate study in Latin America, the protective effect of water quantity was seen only at high levels, as the difference in incidence was related to use of more or less
than 5000 litres per capita per month (165 litres per capita per day), (Luna et al., 1992).

In most studies, distance appears to be the most significant water supply factor influencing trachoma. In a review by Esrey et al (1991), four studies were found that demonstrated a median reduction of 30% in trachoma incidence with shorter distances to the home and two studies that showed no relationship. In all cases, the differences in distance, where significant differences in incidence were noted, were related mainly to levels of service and included:

- household connection versus source more than 500m from household;
- water source less than 5 minutes compared to over one hour; and,
- water source less than 30 minutes compared to source over 2 hours.

Only in one study was there a more sensitive measure, the difference being between sources more than or less than 200m distant.

The importance of distance is supported by several other studies on trachoma prevalence (Hsieh et al., 2000; Prost and Négrél, 1989; West et al., 1989). West et al. (1991) concluded that per capita water availability was not associated either with trachoma or facial cleanliness. Bailey et al. (1991) showed that the reduced volumes of water used for washing children’s faces was associated with trachoma, but total per capita volume use was not significantly different between households with children who had trachoma compared to those with no children with trachoma. Several workers have suggested that it is the value placed on the use of water for hygiene rather than source proximity and per capita water collection that acts as a protective measure against trachoma (Bailey et al., 1991; West et al., 1989; Zerihun, 1997).

Most studies of the incidence of trachoma suggest that it is hygiene behaviour that is the primary determinant. For instance, facial cleanliness is noted as being important and appears to function independently of water quantity (West et al., 1989). Furthermore, West et al., (1991; 1996) noted that clustering of cases within communities was important as was the presence of siblings with trachoma within
individual households. In rural areas, research suggests that factors such as cattle ownership are also important and that sanitation and garbage disposal are important in both urban and rural areas (Emerson et al., 2000; Hsieh et al., 2000; West et al., 1996; Zerihun, 1997).

Other infectious skin diseases have been less well researched, but in a review of influences of socio-economic conditions and skin disease in rural Tanzania, Gibbs (1996) found that household density and low socio-economic conditions was an important determinant for incidence of transmissible skin disease. The study compared two villages and found that distance to water source was not significantly associated with skin disease, despite one village having a water source within half the walking time distance of the other.

1.5.1.3 Understanding the findings of health impact studies

The studies reviewed above suggest that there is a complex relationship between different interventions and disease and contradictory findings are often presented, particularly for diarrhoeal disease. It has been noted by Payment and Hunter (2001) that estimates of risk derived from consuming contaminated drinking water are difficult as these are influenced by water source type, water quality, socio-economic factors and behavioural factors. Prüss and Havelaar (2001) note that for many infectious diarrhoeal diseases, exposure-risk relationships are poorly understood and therefore there are profound difficulties in attributing outcomes to specific exposures.

Esrey (1996) notes that one problem with interpreting the findings for policy use is the lack of longitudinal studies of disease incidence in relation to water and sanitation improvements, although other workers suggest that over-estimation may equally occur and therefore cross-sectional studies are bias-neutral (Jamie Bartram personal communication, 2002). Cairncross (1993) notes that the survival of different pathogen types is favoured by different temperature and moisture conditions, which may also influence infection and morbidity patterns throughout the year. Cairncross (1990b) notes that peaks in diseases caused by bacterial pathogens in developing countries are often noted with the onset of wet seasons, in particular at the start of the wet season. In many developing countries, where many households rely on small, untreated water...
supplies, the peak in bacterial infections coincides with a significant deterioration in microbial quality of the water sources (Barrett et al., 2000a; Gelinas et al., 1997; Wright, 1986).

A significant criticism of many of the studies into the impacts of interventions on diarrhoeal disease is that typically very limited data on water quality have been presented and that significant assumptions are made with regard to the quality of ‘improved’ water sources (Handzel, 1998). Studies by Payment et al. (1991) in Canada add further difficulty in assessing the reliability of the impact studies as they showed that 35% of gastro-intestinal disease could be attributed to consuming water meeting current standards for microbial quality.

In a review of waterborne pathogen transmission and virulence, Ewald (1991) demonstrated that different pathogens have different principal modes of transmission and different virulence. These differences were noted both between different species of pathogen and between different strains of the same species (e.g. between classical *V. cholerae* and *el tor* *V. cholerae* and between different strains of *Shigella spp.*). Ewald concluded that pathogens that were primarily waterborne tended to have greater virulence than those that were primarily non-waterborne.

Ewald (1991) suggests that improvements in water quality would be more effective in reducing morbidity and mortality resulting from more virulent pathogens than other interventions such as excreta disposal and improving hygiene. He further concluded that where other interventions, such as increased water quantity and excreta disposal led to greater reductions in morbidity, this was due to the predominance of less virulent, non-waterborne pathogens. Furthermore, he noted that the failure to consider the principal route of transmission, virulence and evolutionary changes in pathogens was likely to under-estimate the long-term net benefit from good water quality and may be counter-productive in terms of improved health.

In a review of evidence for establishing targets for water quantity and availability, Howard and Bartram (2003) conclude that the findings of available studies are most readily understood as demonstrating the significant impact of all interventions. They
further conclude that the scale and relative impact of a single intervention depends strongly on the pathogen and the dominant route of exposure under local circumstances.

In summary, the evidence shows that diarrhoeal diseases may be transmitted by a variety of routes, all are based on faecal-oral transmission and may be directly waterborne or water-washed. The available evidence from health studies suggests that interventions are likely to be locality-specific and are determined by timing and the interaction between different factors.

The conclusions from health impact studies tend to consistently advocate that greater integration is required in water and sanitation programmes to address water quality, improved quantity and availability, excreta disposal and hygiene education (Esrey et al., 1991). There has been some discussion regarding the policy questions that arise regarding the timing of interventions, given current knowledge of the efficacy of different interventions. As noted by Vanderslice and Briscoe (1995) as all the interventions deliver some improvement, the relative impacts of each are of little relevance for policy and point to the practical implications for water and sanitation programmes in which the initial expressed demand is usually for water supply.

1.6 The surveillance of water supply

WHO defines surveillance as being: 'the continuous and vigilant oversight of drinking water supplies from a public health perspective' (WHO, 1993). Previous definitions have included references to the safety and reliability of the water supply (WHO, 1976). These definitions place surveillance within the sphere of monitoring and assessment with associated implications for data collection. In order that the function and implementation of surveillance programmes in urban areas can be properly designed, it is important to review the available evidence for the effectiveness of monitoring programmes and the demands placed upon them in relation to information needs.
1.6.1 Monitoring and management

Several authors note that monitoring often fails to attract support as it is perceived as an expensive process of acquiring data that yields little observable benefit to decision-makers and end-users (Adriaanse and Lingard-Jørgensen, 1997; Ongley, 1998). Several authors have noted that many monitoring programmes fail to identify information users and their information needs (Adriaanse, 1997; Ongley, 1997; Ongley, 1998).

Adriaanse (1997) emphasises that the information to be collected must be geared towards answering particular questions that are of interest to management decision-making. Timmerman and Mulder (1999) suggest that critical to this process is an initial stage of defining the scope of the information required and to ensure that there is clarity about the 'question' that is being asked, rather than concentrating on the means to collect data to provide an 'answer'. Both authors suggest that this process not only ensures that monitoring programmes provide the information required, it also increases cost-effectiveness as the resources required are targeted on collecting data that will provide information to deliver solutions to identified problems. Critical to this process is to transform data into information, therefore appropriate data analysis and interpretation has been identified as essential to effective monitoring (Ward et al., 1986). Such measures include both statistical and graphical presentation of results geared to the needs and understanding of the target audience (Adriaanse, 1997; Timmerman and Mulder, 1999; Ward et al., 1986).

In discussing the broader field of monitoring and assessment, Adriaanse (1997) and Ongley (1997) point to the importance of resolving issues related to the policy environment and institutional arrangements as being critical for the implementation of monitoring programmes. Adriaanse (1997) also notes that effective institutional arrangements will assist in the identification of target audiences and their associated information requirements. Timmerman and Mulder (1999) point out that target audiences include users or consumers of water. Such acceptance is important when considering the needs of developing countries where responsibility for management of water supplies has been devolved to communities (WELL, 1998).
The types of information required are expected to vary between countries and in relation to the water body or management issues raised. However, the emphasis on collection of large amounts of data through sophisticated means may often not yield the information required (Timmerman and Mulder, 1999). Ongley (1998) suggests that the paradigm of 'data-rich' monitoring programmes derived from wealthy countries are inappropriate for developing countries where the technical, financial and human resources are more limited.

In relation to water quality, Ongley (1998) highlights the need for realism in relation to the parameters that are included in monitoring programmes, suggesting that too much attention is paid to parameters that are both difficult to analyse accurately and which are of limited value for decision-making. Bartram and Ballance (1996) and Adriaanse and Lingard-Jørgensen (1997) support this view and relate the selection of variables directly to the objectives of the monitoring programme. WHO (1993) suggests that it is more effective to collect data more frequently on smaller number of parameters that are of importance to health than infrequent assessment of a wide range of parameters, many of which are of limited value. Within the collection of such data, the importance of data quality is consistently promoted as being an important factor in effective monitoring programmes, in order to provide assurance regarding reliability of the data (Adriaanse and Lingard-Jørgensen, 1997; Ongley, 1998; WHO, 1993).

Although much of the debate in the value of monitoring has focused on water quality, a similar set of conclusions could in general be drawn from other indicators of water supply. Briscoe (1996), Cairncross and Kinnear (1992) and Zerah (2000) all suggest that data on aspects such as costs of water and reliability of water supply are not routinely collected, despite their apparent importance to the users of water supply. Assessments of access or coverage appear only to be undertaken by national authorities during censuses and demographic health surveys. In addition, regular global assessments of water and sanitation coverage are undertaken by WHO and UNICEF under their Joint Monitoring Programme, the most recent being in 2000 (WHO and UNICEF, 2000).
In order to provide a sound basis for surveillance and to therefore identify the policy and institutional elements required to support effective surveillance, the objectives for surveillance should be clear (WHO, 1976; WHO, 1993). Bartram and Ballance (1996) note that establishing clear objectives will help provide answers to questions regarding institutional and policy requirements as well communication strategies and use of data in developing management actions.

The definition by WHO (1993) regarding the health oversight function for surveillance suggests that identification of public risks should be a principal objective of surveillance. Further objectives and questions can be identified to provide further refinement of the monitoring programme. These may include aspects such as compliance with standards and norms, environmental health trends, trends in water supply adequacy and evaluations of specific interventions (Adriaanse, 1997; WHO, 1997).

WHO (1997) has also defined surveillance as being an investigative activity that is designed to identify faults in water supplies, evaluate their importance to health and identify appropriate actions to improve the water supply. This definition suggests that a second objective should be to address the design, construction, operation and maintenance of water supplies in order to assess whether these are adequate and to recommend improvements where required. The issues raised in section 1.3 in relation to the urban poor of unequal distribution of access to services, of greater expenditure on water supply and high water-related health burden; suggest that a third objective should be to assess whether certain communities suffer disadvantages in relation to water supply. Meeting this objective should also logically address how the needs of the urban poor can be met. Commentators have also pointed to the need to target surveillance in urban areas that are at greatest risk from water-related disease, particularly residents of slums and fringe settlements (Lloyd et al., 1991; WHO, 1976).

Within this thesis, it is suggested that these three key objectives can provide the overall direction in developing the monitoring programme and are re-phrased and re-ordered below:
1. To assess water supply and to identify the potential risks to health derived from poor water supply(s) or water handling;
2. To assess whether certain groups are particularly disadvantaged from inadequacy of water supply;
3. To identify what actions would lead to improvement in the water supply and likely health gain or reduced social disadvantage.

These overall objectives help define what data should be collected and the information needs required. They also help in identifying target audiences, which may be expected to include health professionals, water suppliers, policy makers and planners and communities (WHO, 1997). The purpose of this thesis is to review whether surveillance programmes can be designed to meet these key objectives in urban areas of developing countries in a cost-effective and sustainable fashion.

**1.6.2 Institutional issues and implementation of surveillance**

Despite the recognised importance of institutional development within the water sector, relatively little literature explicitly deals with the functions of surveillance, although much of the literature focuses on the regulation of water supply (World Bank, 1993). However, this in itself may lead to institutional difficulties as regulation necessarily encompasses a wide range of functions that may not be wholly related to health issues (WHO, 1997).

Lloyd *et al.* (1991), Lloyd and Helmer (1991), WHO (1993) and WHO/SEARO (1995) emphasise the need for a legal basis for the establishment of a surveillance body. These authors argue that without some legal mandate for surveillance, little action may result from the data collected and recommendations made by surveillance programmes.

The issues concerning institutional responsibility and mandate and the problems related to establishing an effective institutional framework for water supply surveillance reflect broader institutional and organisation concerns in the water sector (Howard, 2002; WHO, 1993). Overall, institutional development has frequently been weak in the water sector in developing countries with a multiplicity of players,
considerable overlap in responsibilities and conflicts of interest within individual institutions that attempt to oversee and implement water supply investments (World Bank, 1993).

Evidence from previous work suggests that there are two distinct but complementary activities required in relation to surveillance: quality control undertaken by a water supplier to demonstrate due diligence; and, independent verification through surveillance (Lloyd et al., 1991; Lloyd and Bartram, 1991; WHO, 1993). Bartram (1996) and WHO (1993) conclude that both are required to achieve improved water supply and that the agency responsible for surveillance should not be directly involved in water supply provision. However, an emphasis is placed on the need for inter-sectoral collaboration in improving the quality of water services (WHO, 1997).

In some circumstances, complete institutional separation may not be technically feasible or financially viable (Bartram, 1996; WHO, 1997). For instance, Bartram (1996) and WHO (1997) note that where there are small, community-managed supplies it is unlikely that the development of a full programme of quality control monitoring by the community will be possible, although some elements may be developed. Bartram (1996) also notes that in some cases the development of parallel activities, where water is supplied by the same body as would normally be expected to function as a surveillance agency, may not be justifiable due to limits on the resources available. This may have further implications when the use of water quality results are translated into regulatory processes (Helmer, 1987).

WHO (1993; 1997) recommends that surveillance be undertaken by health bodies and note that the benefit of responsibility for surveillance lying with the health sector is that it allows the health dimension to become paramount. WHO/SEARO (1995) indicated that in some cases the environment sector could undertake surveillance where the health sector was weak but stress the need for involvement of health professionals.

Models for surveillance in developed countries are mixed. In some countries, for instance the UK and USA, the surveillance function is at least in part discharged by
the environment sector - through the Drinking Water Inspectorate and Environment Agency in the UK (within the Department for Environment, Food and Rural Affairs) and the Environment Protection Agency in the USA. In other countries, for instance Australia, the health sector undertakes the surveillance role through setting standards and undertaking some independent monitoring (NHMRC and ARMCANZ, 1996; 2001).

There is significant potential for decentralisation of water supply surveillance (WHO, 1997). As the resolution of many water supply problems in urban areas by necessity involves rapid decisions and local solutions, there is a strong rationale that decentralised monitoring should be developed (Howard and Luyima, 1999; Howard, 2002). This reflects the general recognition that devolving responsibility for water supply to the lowest feasible level encourages greater sustainability in the delivery of services (Briscoe, 1996; World Bank, 1993). Lloyd et al. (1991) note that in Peru implementation by local environmental health departments in both rural and urban areas was successful.

1.6.2.1 The role of the Non-Governmental sector

In guidance for the surveillance of small, community-managed water supplies, WHO (1997) suggest that implementation of surveillance could be delegated to Non-Governmental Organisations (NGOs). There is some experience of NGOs undertaking surveillance projects in urban communities, although these have tended to be limited in scope and have focused primarily on one or two communities within an urban area. Howard (1997a) describes one project in Mexico City that was undertaken by the Red Cross in two informal communities. The projects aimed to improve water supply quality and hygiene with a view to ultimately transferring responsibility for surveillance to the local environmental health body. Whilst the work in improving water supply and hygiene at the community level showed significant success, handover to the local Government proved to be difficult and only occurred for one settlement as it became formalised (Howard, 1997a).

In other countries, NGOs have proved effective in determining water quality problems in poor communities and using this information to make improvements in water
supply in urban and rural areas (Breslin, 2000; Nick Hepworth 2000, personal communication). However, the direct relationships with a Government surveillance body have often been limited and rarely on the basis of delegation of responsibility.

The role of NGOs may be important where there is a significant number of informal settlements, which may be at greatest risk from poor health. Hardoy and Satterthwaite (1989) note that Governments may be reluctant to extend any form of service to such communities and if there is an antagonistic relationship with Government, the communities may themselves be reluctant to allow Government staff to enter the community. Such situations may represent areas where NGOs and other community groups may be better placed to undertake surveillance activities. However, the relationship between NGOs and Government requires careful definition and must be accepted by both the NGOs and official surveillance body, which may not always be readily achievable.

1.6.2.2 Community involvement

Direct community involvement in surveillance and monitoring water supplies is an area where there is increasing interest (WHO, 1997). This mirrors the much longer-standing approach to water supply delivery in developing countries that emphasises the role of community-management. In surveillance activities undertaken in Peru in the late 1980s, some degree of community involvement in the process of monitoring of water quality was implemented through training communities in the use of sanitary inspection (Lloyd et al., 1991; Lloyd and Helmer, 1991).

Breslin (2000) describes a recent project in South Africa, where water quality monitoring was directly linked to a participatory health education programme, and reports that the programme was effective in improving water quality. This programme introduced simple kits for testing total coliforms that could be used by children and other community members to test the water, for which chlorination was available in some cases. Results were discussed with the community and problems with the water supply were identified through discussion with community members.
Despite the success noted by the South African project, some serious reservations remain. The use of total coliforms as the indicator for microbiological quality is questionable, as discussed in Section 2.2. In the project it was outlined that communities used presence of total coliforms to indicate that faecal contamination had occurred, a conclusion that could not be justified. It should be noted, however, that the research team recognised this weakness and were promoting \textit{E.coli} as a preferred indicator (Breslin, 2000). However, it was unclear how communities would perform such analysis.

There is limited available literature that describes how community-based monitoring and surveillance can be effectively implemented in urban areas and the information that does exist indicates that the role of communities in implementation of surveillance in urban areas requires careful consideration. Many of the water sources available are likely to be linked to some form of utility water supply. Therefore, communities could legitimately expect that the water supplier should be required to take proper care in ensuring that water delivered is of high quality and that action is taken to rectify any faults noted (WHO, 1976).

Furthermore, as discussed in Section 1.3, a significant number of urban households will be involved in earning income through employment and business, which may limit the amount of time available for additional responsibilities in monitoring water supply. However, at the same time, as many households utilise communal sources there is clearly a need to consider the use of communities in monitoring water supplies. There are increasing attempts to transfer operational responsibility to communities of small towns through water user associations and groups (Subramanian \textit{et al}., 1996). In this case, there is a need to address the capacities of such organisations to undertake basic routine monitoring similar to that practised by larger water supply concerns.

\textbf{1.6.3 Use of surveillance data in improving drinking water quality}

The discussion in 1.5.1 highlighted the need for monitoring programmes to respond to management information needs in improving water supply and water handling where water must be transported to the home. The use of data and the improvements that can
be suggested and implemented will, by their very nature, be determined by the results of the surveillance and therefore no prescriptive model of information-action linkage can be identified (Lloyd and Bartram, 1991; WHO, 1997). However, the work by Bartram (1999), Howard (2002), Lloyd and Bartram (1991) and Lloyd and Helmer (1991), indicates some key areas where action may be taken on the basis of surveillance data.

There are four main areas of intervention that are expected to be informed through surveillance:

1. Technical and environmental improvements in water supplies and water in the home (Bartram, 1999; Howard, 2002; Lloyd and Bartram, 1991; Lloyd and Helmer, 1991);
2. Educational interventions designed at improving water management in communities and within the home (Howard, 2002; Lloyd and Helmer, 1991);
3. Regulation to enforce compliance with standards (Howard, 2002; Lloyd and Helmer, 1991); and,
4. Action in the broader policy arena that supports improved water supply (Bartram, 1996; Howard, 2001; Howard, 2002).

It should be noted that these cover a range of levels at which action is expected. To support this, data from a number of indicators, such as the costs, reliability, accessibility and quantities of water, may be required to improve water supply quality (Lloyd et al., 1991; Lloyd and Helmer, 1991; WHO, 1997). Previous studies in Peru demonstrated that data collected through a surveillance programme had a significant impact on the quality of service provided by vendors using tanker trucks (Lloyd et al., 1991). In this programme, the problems encountered by the vendors in collecting water from hydrants were caused by regular discontinuity in the piped supply, which led to hardship in the low-income areas primarily served by vendor supplies. The surveillance agency was able to persuade the utility to maintain constant pressure at the hydrants so that reliability of supplies could be improved. The surveillance agency also recommended that regular disinfection of the tankers should be performed and hygiene education be undertaken in the communities affected. In Ghana, similar action was taken by a water supplier when improving their monitoring programme
(Jonas Jabulo 2001, personal communication). There is also evidence of strategies to improve point sources of water supply in urban areas in order to reduce health risks (Gelinas et al., 1997; Howard et al., 2001a).

The use of surveillance data to improve technical specification and operation and maintenance of supplies is taken as the principal function of surveillance in many developed countries, partly operating through a regulatory function (WHO, 1993). Work by Lloyd et al. (1991) was able to show that evaluation of treatment technologies in rural areas and small towns could lead to improvements in design and operation that led to sustained improvements in water quality. Whilst similar findings would be expected for larger urban utility supplies, Howard (2002) notes that there is greater evidence that such improvements are driven by the water sector rather than the surveillance agency. Thus, whilst recommendations are made to change or improve water treatment processes, the degree to which the surveillance agency can ensure this occurs is less clear.

The importance of improving water treatment performance is not always obvious given the often low rates of connection and significant use of alternative supplies (Howard and Luyima, 1999; WEDC and RCPEH, 1999). Furthermore, the relative severity of contamination in different forms of water supply and in water stored in the home may need to be evaluated and interventions to improve water quality may be more important in alternative supplies or through hygiene education (WHO, 1997).

Interventions to improve household treatment of water have also been noted to be effective. Research by several authors shows that simple, low-cost household disinfection systems are capable of causing a significant improvement of drinking water quality and greatly reduced incidence of diarrhoeal disease (Hanzel, 1998; Mintz et al., 1995; Quick et al., 1999; Semenza et al., 1998). The success of household level treatment in these studies suggests that there is significant scope for improving water quality for the urban poor through simple, point of use disinfection strategies. Experience with direct household storage interventions are less well documented, but could be seen as feasible provided programmes engage households directly in discussions of why and how water quality deteriorates.
Surveillance data could also be expected to have an input into the development of hygiene education programmes. In work carried out in South Africa, Breslin (2000) reports that water quality data could be closely linked to a participatory health education programme. Approaches that maximise the potential for households to participate in defining problems and solutions mirrors a general trend to more participatory approaches to hygiene education through experiential learning (Hubley, 1993).

The examples highlighted above primarily relate to the improvement in water quality. However, as information may be required on a broader range of indicators, it is pertinent to discuss how such data could also be used to promote improvements in supply. Surveillance data may be used by the health sector in identifying areas more prone to infectious water-related disease and as a planning tool for preventative and curative services. Lloyd et al. (1991) demonstrated the value of combining water supply adequacy and health data in identifying particularly disease-prone areas.

Within the policy environment, there is increasing recognition for need to develop more effective regulation of water supplies (Mwanza, 2001; World Bank, 1993). Regulation is seen to confer benefits as it requires water suppliers to ensure that the services provided are adequate and of limited risk to health (WHO, 1993; 1997). However, as noted during a recent WEDC Conference in Lusaka, Zambia, although regulation may provide benefits in improving the water supply, it must also include targets for serving populations with currently limited access to water supplies (Ian Smout 2001, personal communication). Helmer (1987) highlighted the need for regulation to take into account socio-economic levels of development and suggested that regulation was only one tool available for promoting improvements in the water sector and that educational and other policy interventions may also be required.

1.7 Aims and Objectives

The previous sections have highlighted the nature of urban settlements in developing countries and the impact that this has on poverty, health and water supply. The evidence suggests that there is a significant health burden that is derived from poor water supply and that this is primarily carried by the urban poor. The need for the
collection of data on water supply has also been described, as has the need to address a range of aspects of water supply to enable surveillance programmes to assess water-related risks to health. The need to consider information needs and target audiences has also been discussed, as have the links between surveillance and improvement.

Low-income countries are also increasingly recognising the need for such independent oversight, but adoption of models used in the developed countries have proved of limited value given the very different rates of access to high quality water supplies and often weak legal frameworks that would promote such oversight. The nature and focus of surveillance in urban areas of developing countries may well need to be different from that in developed countries, with less emphasis placed on regulations and standards and greater emphasis on advocacy, incremental improvements in water supply and hygiene education. This thesis will address the development of a model for surveillance of water supply that is appropriate for low-income countries.

The limited development of water supply surveillance programmes in urban areas indicates the need to develop a model for surveillance that is appropriate to the conditions and nature of urban settlements in developing countries.

### 1.7.1 Aim of the study

The aim of this thesis is to develop a model of water supply surveillance for urban areas of developing countries that provides reliable assessment of water supplies, with particular emphasis on the urban poor. The thesis will also address how this information may be used to develop appropriate management actions to improve water supply and hygiene amongst poor urban communities.

### 1.7.2 Objectives of the study

1. To identify and review available indicators of water supply that can be used to describe water-related risks, and the means of measurement of the indicators.
2. To test the indicators selected in the review in the field to assess their ease of measurement and robustness.
3. To test methodologies for identifying vulnerable groups in urban areas and identify those that are reliable and which ensure surveillance targets the urban poor.

4. To assess the most appropriate institutional arrangements that are supportive of surveillance and improvement of water supplies at local and national level.

5. To test whether improvements in water supply can be developed and implemented on the basis on surveillance data that operate for the benefit of the urban poor.

6. To identify appropriate means of data management and analysis that supports policy and management decisions.
Chapter Two

Review of available indicators

2.1 Introduction

The effective implementation of surveillance as a health-related activity requires that indicators are selected which are relevant, reliable and quantifiable (Howard, 2002). As discussed in the previous section, a range of indicators may be required in a surveillance programme, as a number of aspects of water supply may influence health.

This section will identify and review water supply indicators reported in the literature and evaluate their efficacy and means of measurement. The chapter concludes with a set of indicators selected that have been identified as most appropriate for surveillance programmes in urban areas. These are the indicators that were subsequently tested in the field studies.

There are six major indicators of water supply identified from the literature that have been commonly used in monitoring water supply in urban areas (WHO, 1976; 1997; World Bank, 1993). These are:
1. Quality of domestic water;
2. Quantities of water available and used for domestic purposes;
3. Reliability (or continuity) of the water supply;
4. Costs of securing domestic water supply;
5. Accessibility of domestic water supplies; and,
6. Unaccounted-for-water within domestic supply.

2.2 Water quality

The influence of microbiological quality of drinking water in the transmission of infectious diarrhoeal diseases has been discussed in section 1.4. Adverse health consequences may also be found from the consumption of water with toxic levels of chemicals. Other aspects of water quality which make the water unpalatable and which may lead to abandonment of otherwise safe drinking water supplies (WHO, 1993; 1996a). All these parameters therefore warrant consideration when planning a water supply surveillance programme. This section will address the importance of different parameters for health and their priority in developing countries and will also review the means by which water quality can be measured.

2.2.1 Microbiological quality

There is a wide variety of micro-organisms that may be found in water (WHO, 1993). These include those that are pathogenic (that is can lead to infection in a human host) and those that are non-pathogenic, which are likely to be the dominant group of micro-organisms. The presence of some non-pathogenic micro-organisms may lead to other problems in water supplies, such as taste and odour, which may be of particular importance to users of the supply as an indicator of safety and may influence selection of water for consumption (McGuire, 1995). Since the work of John Snow in the 1880s, the priority in water quality control has been the elimination of pathogenic micro-organisms that represent a risk to human health (Trussel, 1999; WHO, 1996a).

2.2.1.1 Water-borne pathogens

The majority of the pathogenic micro-organisms of concern are derived from human faeces and to a lesser extent from animal faeces (WHO, 1996a). Four major groups of micro-organisms exist: bacteria, helminths, protozoa and viruses. WHO (1996a) have
provided an indication of the range of different pathogens that may be found in drinking water, with the severity of their health effect, persistence in water and infectious dose, as shown in table 2.1. As this table illustrates, infective dose and persistence in water varies widely and animal reservoirs are important for some pathogens.

<table>
<thead>
<tr>
<th>Pathogen</th>
<th>Health significance</th>
<th>Persistence in water supply</th>
<th>Relative infective dose</th>
<th>Important animal reservoir</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bacteria</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Camplyobacter jejuni, C.coli</td>
<td>High</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Yes</td>
</tr>
<tr>
<td>Pathogenic E.coli</td>
<td>High</td>
<td>Moderate</td>
<td>High</td>
<td>Yes</td>
</tr>
<tr>
<td>Salmonella typhi</td>
<td>High</td>
<td>Moderate</td>
<td>High</td>
<td>No</td>
</tr>
<tr>
<td>Shigella spp.</td>
<td>High</td>
<td>Short</td>
<td>Moderate</td>
<td>No</td>
</tr>
<tr>
<td>Vibrio cholera</td>
<td>High</td>
<td>May multiply</td>
<td>High (?)</td>
<td>No</td>
</tr>
<tr>
<td>Pseudomonas aeruginosa</td>
<td>Moderate</td>
<td>May multiply</td>
<td>High (?)</td>
<td>No</td>
</tr>
<tr>
<td>Aeromonas spp.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Viruses</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adenoviruses</td>
<td>High</td>
<td>?</td>
<td>Low</td>
<td>No</td>
</tr>
<tr>
<td>Entroviruses</td>
<td>High</td>
<td>Long</td>
<td>Low</td>
<td>No</td>
</tr>
<tr>
<td>Hepatitis A</td>
<td>High</td>
<td>?</td>
<td>Low</td>
<td>No</td>
</tr>
<tr>
<td>Hepatitis E</td>
<td>High</td>
<td>?</td>
<td>Low</td>
<td>No</td>
</tr>
<tr>
<td>Norwalk virus</td>
<td>High</td>
<td>?</td>
<td>Low</td>
<td>No</td>
</tr>
<tr>
<td>Rotavirus</td>
<td>High</td>
<td>?</td>
<td>Moderate</td>
<td>No (?)</td>
</tr>
<tr>
<td>Small round viruses</td>
<td>Moderate</td>
<td>?</td>
<td>Low (?)</td>
<td>No</td>
</tr>
<tr>
<td>Protozoa</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Entamoeba histolytica</td>
<td>High</td>
<td>Moderate</td>
<td>Low</td>
<td>No</td>
</tr>
<tr>
<td>Giardia intestinalis</td>
<td>High</td>
<td>Moderate</td>
<td>Low</td>
<td>Yes</td>
</tr>
<tr>
<td>Cryptosporidium parvum</td>
<td>High</td>
<td>Long</td>
<td>Low</td>
<td>Yes</td>
</tr>
<tr>
<td>Helminths</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dracunculus medinensis</td>
<td>High</td>
<td>Moderate</td>
<td>Low</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Table 2.1: Water-borne pathogens (adapted from WHO, 1996a)

Early work in the control and monitoring of water quality was focused on the prevention of epidemics of cholera, typhoid and dysentery that affected Europe and North America (Gleeson and Gray, 1997; Tebbut, 1998). Olson and Nagy (1984) note that many of the improvements in water supply undertaken by sanitary pioneers led to
significant reductions in disease incidence, even though the agents causing the outbreaks were often unknown. As many of these epidemics were related to bacterial pathogens, much of this work focused on the control of such pathogens, rather than other agents. Gleeson and Gray (1997) show that other types of water-borne pathogens have become increasingly important.

The importance of bacteria as agents of severe acute disease is still evident as they account for a significant proportion of cases of diarrhoeal disease of known aetiology in both developed and developing countries (Ford, 1999). Coldwell (1999) and Haas et al. (1999) note that global epidemics of cholera form part of the 7th pandemic, which started in the 1960s. There also continue to be well-documented epidemics of Shigella and bacterial dysentery related to water (Nasinyama et al., 2000; Pegrarn et al., 1998). This affects developed as well as developing countries and an outbreak in 2000 in Walkerton, Canada of E.coli O157:H7 and Campylobacter jejuni led to 7 deaths and 2,300 people suffering acute infection (O'Connor, 2002). Haas et al. (1999) note that bacterial infections, notably from Campylobacter jejuni continue to exert a significant disease burden on populations in developed and developing countries.

The importance of viral and protozoan pathogens in causing both endemic and epidemic diarrhoeal disease is increasingly recognised and the control of these pathogens is receiving significant attention (Friedman-Huffman and Rose, 1998; Okun, 1996; Taylor et al., 1997; WHO, 1996a). Several viruses have been linked to epidemics in low and middle-income countries as well as contributing to endemic diseases. These include Hepatitis A and E virus, rotavirus, adenovirus and Norwalk virus (Ford, 1999; Grabow, 1996; Rab et al., 1997; WHO, 1996a). Rab et al. (1997) describe a Hepatitis E outbreak in Islamabad, Pakistan, that was traced to a malfunctioning treatment plant. Grabow (1997) notes that Hepatitis E virus has been responsible for several large-scale outbreaks in developing countries, including one in Delhi that for 20 years had been considered to be due to Hepatitis A virus. Grabow (1997) also notes that numerous outbreaks have been due to Hepatitis A virus, for instance an extreme case of 300,000 cases in Shanghai, China. In addition to recognised outbreaks of waterborne viral disease, it is now suggested that a large
proportion of diarrhoeal diseases of unknown aetiology are likely to derive from viral pathogens and in particular rotaviruses (WHO, 1996a).

Protozoan pathogens also attract increasing attention and within this group, giardia and entamoeba have been recognised as important human pathogens for a number of years (Haas et al., 1999; WHO, 1996a). More recently, cryptosporidium has attracted more attention, as this has led to high profile outbreaks of diarrhoeal disease in developed countries, including one outbreak in which 400,000 people were infected in Milwaukee, USA and led to high rates of fatality among immuno-compromised groups (Hellard et al., 1997; Okun, 1996; McKenzie et al., 1994). There are limited studies of cryptosporidium infection in developing countries, although Nacro et al. (1998) showed that cryptosporidiasis was a major factor in diarrhoea in paediatric hospitals of Burkina Faso. Kelley et al. (1997) reporting on a study in Lusaka, Zambia found that there were higher rates of infection with cryptosporidium and greater incidence of diarrhoea among adults using water from a surface source that was found to contain Cryptosporidium parvum.

Helmer et al. (1999) note that despite the abundant evidence of pathogens in water and their role in infection, the measurement and derivation of pathogen values that represent ‘safety’ in terms of microbiological quality of drinking water have proved difficult to define. These authors note in particular that generalised infective doses (and therefore allowable concentrations in drinking water) are difficult to determine, as there are many confounding factors. Grabow (1996) notes that confounding factors include varying susceptibility between individuals, poor diagnosis of etiological agents, prevalence changes due to socio-economic and geographic factors and sub-clinical infections.

Gleeson and Gray (1997) note that whilst analytical methods for pathogen detection are improving, many remain difficult and often prohibitively expensive. Gleeson and Gray (1997) and WHO (1996a) question the value in testing for pathogens in water, as this would have little predictive value because it would be likely that during the time taken to obtain a result, water containing pathogens had already been consumed.
A key concept in monitoring of microbial quality of water should support preventative action before a significant health problem occurs (WHO, 1996a).

Pipes et al. (1986) also note that the wide range of pathogens that may be present in water places limitations on the value of the analysis for any individual pathogen. WHO (1996a) points out that because the presence or absence of a particular pathogen in a water supply cannot provide an overall indication of the likely presence of other pathogens, care must be taken in interpreting the results of pathogen analysis. As a result of these problems and because pathogens are commonly associated with faecal contamination, the identification of indicator bacteria was an early development in the monitoring and control of water quality (Helmer et al., 1999).

2.2.1.2 Indicator bacteria

The purpose of indicator bacteria is to provide a simple mechanism to screen whether there is a risk of pathogen presence in drinking water (Helmer et al., 1999). The criteria for ideal indicator bacteria have been outlined by Cabelli (1978) and these can be summarised as:

1. Present whenever pathogens are present.
2. Present in the same or higher numbers than pathogens.
3. Specific for faecal or sewage pollution.
4. At least as resistant as pathogens to conditions in natural water environments, and water purification and disinfection processes.
5. Non-pathogenic.
6. Detectable by simple, rapid and inexpensive methods.

The principal indicator bacteria currently used are from the coliform group. These are Gram-negative, non-sporing, rod-shaped bacteria capable of aerobic and facultative anaerobic growth in the presence of bile-salts (and other surface active agents with similar growth-inhibiting properties) which are able to ferment lactose with the production of acid and gas within 48 hours at 37°C. (Anon, 1982). Of these, Escherichia coli (E.coli) is the principal faecal indicator bacteria and is able to grow at 44°C. E.coli is a member of a more general group of coliforms referred to as
thermotolerant, which are a generally accepted surrogate for *E.coli* (WHO, 1993). The total coliform group is also commonly used, although this group contains many species that are not faecal in origin.

Ashbolt *et al.* (2001) suggest that the current indicators have serious limitations and that the relationship between pathogens and indicator bacteria is not a simple one. The range of pathogenic organisms is large, their characteristics are broad and many do not bear significant similarities with indicator organisms generally used (Gale, 1996; Grabow, 1996; Ashbolt *et al.*, 2001).

There are also concerns regarding environmental persistence and multiplication, as there is evidence that thermotolerant coliforms may contain species of non-faecal source (WHO, 1996a). There have also been suggestions that *E.coli* in tropical water may have an environmental source. Hazen and Torranos (1990) reported finding *E.coli* in rainwater taken from leaves from 'pristine' rainforests where there was no obvious source of faecal matter. This study, however, appears to have overlooked the possibility that *E.coli* could be derived from rodent and bird faeces, and that as noted by WHO (1996a) faeces from these sources may contain pathogens. Therefore, these conclusions should be treated with some caution. More recent research suggests that *E.coli* can multiply in contaminated soils in tropical climates, although the authors of the study also stated that in most cases they would be out-competed by other environmental bacteria (Byanppanahalli and Fujioka, 1998).

Research by Payment *et al.* (1991) and Payment (1998) provide further evidence of weaknesses of current indicators in predicting health risks, as they recorded evidence of infection by waterborne pathogens taken from water supplies where no indicator bacteria were isolated. It has been suggested that whilst the current suite of indicators of microbiological quality have provided a useful tool for controlling epidemics of waterborne disease, they provide far less information about endemic disease, particularly where the disease agents are viruses (Payment, 1998). A recent study in Melbourne, Australia, concluded that there was no evidence for infectious diarrhoeal disease that could be ascribed to water meeting current guidelines for indicator bacteria in a supply with a highly protected catchment (Hellard *et al.*, 2001). The
authors also concluded that supplies with more degraded catchments would represent a much higher risk and that the current indicator organisms could not be relied upon alone to predict pathogen presence or public health risk. In developing countries, the catchments for source waters for urban supplies (whether piped or non-piped) are commonly poorly protected and therefore would be expected to be similar to the conditions found in the Payment studies rather than the Hellard et al. study.

The presence of pathogens in the absence of indicators has also been found in rainwater collected by households in Port Harcourt in Nigeria (Uba and Aghogho, 2000). In a study of rainwater collected from a variety of roof materials, Shigella spp. and Salmonella spp. were isolated whilst neither faecal coliforms nor faecal streptococci were isolated from any rainwater collected. These results appear surprising, however, as it might be expected that the standard indicator bacteria would have been found in such circumstances, as both would generally be considered to be more environmentally robust than Salmonella spp. and Shigella spp. (WHO, 1996a).

Although the presence of pathogens in the absence of indicators is partly due to the different nature of viral and protozoan pathogens and bacterial indicators (Ashbolt et al., 2001), it may also be as a consequence of differences in analytical methods. Gale et al. (1997) note that volumes of water analysed for pathogens may be up to one thousand times greater than those analysed for indicator bacteria. They suggest that using the same volume for indicator analysis may well result in greater sensitivity in isolating indicator bacteria.

LeChevalier (1999) further questions the use of the coliform group as a faecal indicator in piped water supplies, as many coliforms isolated may be derived from biofilm systems. The health significance of biofilm within distribution systems remains uncertain as the majority of the microbes found in such formations are likely to be environmental in nature and have little or no pathogenicity for humans (Geldreich, 1996).
2.2.1.3 Supporting evidence for retaining current indicators

The discussion above indicates that there are significant limitations in the use of *E. coli* and thermotolerant coliforms as indicators of microbiological quality of health relevance. However, there are convincing arguments that can be made for the continued use of *E. coli* and thermotolerant coliforms, in particular their recognised value in relation to the control of waterborne epidemics (Lee, 1991; Payment, 1991). A recent review of microbial indicators concluded that the use of the standard indicators has done much to improve health and their abandonment due to recognised weaknesses is unjustified and likely to be counter-productive to health (OECD and WHO, 2001).

If the current indicators are to be retained, it is of value to consider the ways in which these may be most effectively used. To do this, it is useful to consider how data from analysis of microbial indicators have been interpreted and to highlight how deviations in interpretation from the original use of indicators may have weakened their value. The original development of standards for water quality in the early 20th Century were designed to verify treatment system performance, which had been shown to be effective in pathogen removal (Helmer et al., 1999; LeChevalier, 1993; Okun, 1993). Helmer et al. (1999) note that bacterial indicators were only one mechanism of verification of quality that was supported by sanitary surveys of water supplies and by good operational practice in water treatment plants. Over time, however, the basis of legally enforceable measures of water quality has increasingly focused on numerical limit values for faecal indicator bacteria (Helmer et al., 1999).

From discussions between the author and numerous professionals from developing and developed countries, it has become apparent that many people in water sector equate an absence of faecal indicator bacteria with an absence of pathogens. The study by Payment et al. (1991) suggests that this is not the case as discussed above. Furthermore, many professionals also seem to equate the presence of faecal indicator bacteria with confirmation of the presence of pathogens. As noted by Ashbolt et al. (2001), this is not the case but merely implies that there is some evidence of faecal contamination and therefore the potential for pathogen presence has also increased.
Gleeson and Gray (1997) note that there are inherent dangers in relying solely on the analysis of indicator bacteria and quote a range of regulatory documents that highlight that the interpretation of the findings of analysis depends in part on the frequency of sampling and whether sampling programmes are representative. Gleeson and Gray (1997) and WHO (1996a) note that the presence of indicator bacteria cannot be taken as definitive evidence of pathogen presence, but rather that the risk of pathogens being present has increased, particularly where the bacteria used is an indicator of faecal contamination.

It can therefore be concluded that the principal flaw in the use of indicator bacteria in many situations has been to translate the findings of monitoring that describe a risk (which is an inherently probabilistic approach) into a certainty. Such an approach contains some degree of potential for false positive and false negative results in relation to pathogen presence. This is of relevance in that the current application of the faecal indicator bacteria means that action is usually only required when indicator bacteria are isolated.

In terms of direct health consequences, the false negative result is of greatest concern and, as a result, this has tended to be the area where most work has focused (Hellard et al., 2001; Payment et al., 1991; Payment et al., 1993; Payment, 1998). This research has primarily been done in wealthy countries where other aspects of water supply – access, reliability and acceptable costs – are largely resolved.

By contrast, in developing countries, the false positive result may be of equal concern in that it would imply that some form of action (and therefore investment) is required to mitigate a health risk that does not actually exist (Cairncross, 1990a). Given serious resource limitations, this may therefore lead to a focus on improving water quality in supplies that are used by relatively few people and where greater attention to other aspects of water supply improvement, hygiene behaviour or sanitation would yield greater health gains (Cairncross, 1990a). The meaning of true positive should also be carefully considered in the context of multiple routes of infectious disease transmission. In some cases a degree of contamination of drinking water can be
tolerated, with limited increased health burdens, if this means that resources can be allocated to other improvements in water and sanitation.

In this context, the relative numbers of faecal indicators in a water supply may be more important than simple presence, as increasing numbers of indicator bacteria implies that the risk of pathogen presence increases (Lloyd and Bartram, 1991). Whilst this would be most effective for pathogens of similar type (i.e. bacteria) it may still provide some indication of the likelihood of other pathogens being present as they indicate evidence of recent faecal contamination.

Overall, despite the well-recognised limitations in the use of *E. coli*, there remains little evidence for abandoning its use, as *E. coli* presence provides reliable evidence of faecal contamination (Ashbolt *et al.*, 2001). Ashbolt *et al.* (2001) and Gleeson and Gray (1997) note that the term index is more appropriate when interpreting the results of indicator bacteria, as this more accurately reflects the nature of information derived. Furthermore, as noted by Ashbolt *et al.* (2001), the use indicator bacteria must be integrated into a broader set of controls and indicators. Helmer *et al.* (1999) and WHO (1997) conclude that this should include sanitary inspection, protection of water sources and control of treatment processes.

2.2.1.4 Other microbial indicators

Other micro-organisms have been suggested for use as indicators for microbial quality of drinking water, such faecal streptococci, hydrogen-sulphide producing bacteria and bacteriophages (Ashbolt *et al.*, 2001; Moe *et al.*, 1991; WHO, 1996a). To date, recommendations have not advocated routine testing for such microbes in drinking water supplies largely due to the generally lower number excreted and the more time-consuming analysis (Lee, 1991; WHO, 1996a).

Work by Moe *et al.* (1991) in the Philippines suggested that the presence of enterococci in drinking water showed a stronger association with incidence of diarrhoeal diseases than *E. coli* and it was concluded that these bacteria were better indicators for drinking water quality in relation to health. Epidemiological studies amongst users of recreational water have shown that faecal streptococci have a greater
association with diarrhoeal diseases of unknown aetiology, but which are presumed to be viral (Bartram and Rees, 2000). Faecal streptococci have been recommended for routine monitoring of recreational water quality (Bartram and Rees, 2000).

WHO (1996a) indicates that faecal streptococci have greater resistance to environmental stress than *E. coli* and recommended their use when assessing contamination derived from poor hygiene during distribution mains repair and when assessing contamination of groundwater. The disadvantage with the use of faecal streptococci, however, is that the numbers excreted per gram of faeces are lower ($10^5$-$10^7$) than *E. coli* ($10^6$-$10^8$) (WHO, 1996a).

Work by a number of researchers (Grant and Ziel, 1996; Manja *et al.*, 1982; Ramteke, 1995) has focused on the use of hydrogen sulphide producing bacteria as indicators of water quality. This is because analysis can be greatly simplified and costs can be reduced, thus making this test an attractive option for developing countries (Manja *et al.*, 1982).

The test is generally used as a presence/absence test, but can be quantitative. However, there are significant problems with false positives. Sobsey (2002b) reviewed this test and identified a number of problems. Sobsey showed that a wide range of environmental organisms are sulphate-reducers that will produce a positive result when using the H$_2$S strip and performed laboratory experiments that suggested a significant rate of false positives (25%), although the number of samples analysed was small (Sobsey, 2002b). Sobsey also notes that despite literature pointing to adequate performance of the test in relation to other indicator bacteria, there remains a lack of evaluation of the test using generally accepted criteria - such as standard volumes, incubation times and temperatures and media. He notes that this makes meaningful comparisons difficult and suggests that this limits the degree to which the tests should be used.

Sobsey (2002b) also indicates that a further problem relates to potential chemical interference with the tests, particularly when applying the test to groundwater. He notes that because groundwater often contains iron sulphides, there is a significant
potential for false positives resulting from hydrogeochemical reactions. The presence of sulphate-reducing bacteria associated with corrosion of metal rising mains in tubewells, which are commonly found in shallow and deep groundwater, represents a further significant cause of false positives. False positives may also be caused by the degradation of organic wastes and the production of sulphides from bacteria of non-faecal origin. Sobsey (2002b) concluded that there are serious weaknesses in applying this test in shallow groundwater.

Other research has investigated the use of non-bacterial indicators that could be used for analysis of microbial quality of water, in particular to address potential presence of non-bacterial pathogens (Ashbolt et al., 2001; Grabow et al., 1995). Grabow et al. (1995) suggests that bacteriophages (viruses that infect bacteria) have significant potential for use as surrogates for viruses in some applications of water quality assessment. However, Ashbolt et al. (2001) suggest that although phages may be of value as tracers and in studies to understand the movement of viruses in aquatic environments, they cannot be used as indicators of faecal pollution given natural sources in the environment such as vegetation.

The literature suggests that whilst other microbial indicators may be useful in monitoring water quality, none fulfil the criteria required for an ideal indicator any better than E.coli. Therefore, whilst the use of alternative indicators may be encouraged, the continued use of E.coli and thermotolerant coliforms remains justified provided this is supported with sanitary inspection and treatment process control.

2.2.1.5 Means of analysis for thermotolerant coliforms

Analysis of thermotolerant coliforms can be undertaken through a number of different approaches and the selection of the method depends on several factors including the resources available, technical competence of the staff undertaking analysis and the likely quality of the water to be tested.

The two principal methods for enumeration of thermotolerant coliforms are the multiple tube method and membrane filtration (WHO, 1997). In the former, the
analysis of several tubes containing different volumes of sample allows a statistical estimate of the numbers of bacteria in the water and is sometimes referred to as the most probable number (MPN) approach. The MPN technique is widely used worldwide, but it is cumbersome and requires a greater level training in the interpretation of results than alternative approaches. It is effective, however, when samples are turbid and where the organisms are injured (WHO, 1997).

Membrane filtration (MF) is a more recent technique, but one which has been an accepted standard method for many years (Anon, 2000; Geldreich, 1996; WHO, 1993). The advantage of the MF technique is that direct counts of bacteria may be made from colonies grown on filter papers incubated on nutrient media for 14-24 hours. The cost of the technique is often somewhat higher than the MPN method as each test uses a filter and an absorbent pad. The MF technique is also not appropriate where samples are turbid as the filter may block and the suspended sediment may interfere with bacterial growth. The MF technique, however, is easier for non-microbiologists to perform and evidence suggests that this is an appropriate method for developing countries (Bartram and Ballance, 1996; Lloyd and Helmer, 1991).

As microbiological analysis is relatively costly there is interest in developing low-cost methods of analysis. One area of particular interest is the use of presence/absence tests, for which commercial and non-commercial tests are available, as this may provide opportunities to significantly reduce costs (Pipes, 1990). However, as for all components of monitoring, the presence/absence test is only of value if it aids decision-making. With presence/absence tests this will only be in situations when action automatically results from any detected contamination (Pipes, 1990). Logically this would then imply that the use of such tests is restricted to supplies where contamination only occasionally occurs. Water supplies in most developing countries tend to show more frequent contamination and the degree of contamination, requiring enumeration techniques, is more useful in deciding priority interventions (Lloyd and Bartram, 1991).
2.2.1.6 Field and laboratory-based approaches

The analysis of water samples can be carried out in laboratories or through the use of field equipment. A number of field testing kits are available for microbiological analysis, some using MPN approach and some using the MF technique (Bartram and Ballance, 1996).

Although there is often a perception that water quality monitoring must be performed through the use of laboratories, in many developing countries these facilities are lacking. The development of laboratories is expensive and has often resulted in sophisticated facilities that are expensive to use, require specialist trained staff and have limited potential for interactions with communities and users (Howard 2002).

Bartram and Ballance (1996) note that where laboratories are used, there may be problems in sample deterioration during transport from the point of collection to the laboratory and this may be more significant than many experts believe. Microbiological samples should be stored below 4°C and, unless samples can be refrigerated, with analysis performed within 4-6 hours. In many cases, this becomes difficult in developing countries (Bartram and Ballance, 1996). The problems with sample deterioration are not found with field testing kits, where the sample may be processed and incubated on-site (Bartram and Ballance, 1996; Lloyd and Bartram, 1991).

The number of samples that can be processed in one day using field test kits is often limited to between 10 and 20, although this may be increased to 30 in some kits (Bartram and Ballance, 1996). The limits on the number of samples that can be analysed may result in frequent visits being made or using more staff to collect sufficient samples. In the case of frequency of visits, however, this may be a further advantage of field equipment in addressing likely temporal variations (Howard, 2002).

2.2.1.7 Analytical quality control

Analytical quality control in microbiological testing is more difficult than for chemical parameters because the distribution of microbes in water is not homogenous.
at the usual level of detection (Gale, 1996; Gale et al., 1997; Lightfoot et al, 1994; Tillett and Lightfoot, 1995). Lightfoot et al. (1994) note that whilst distribution of chemical substances in water may also be non-homogenous, the variation is noted at the molecular level which is generally below the limit of routine analytical detection in water.

Lightfoot et al. (1994) describe a method for quality control on the basis of a range of values that can be accepted at a 95% confidence level based on binomial theory. These use a duplicate, split-sample approach and a range of acceptable values falling within a 95% confidence level has been calculated, using equation 3.1.

\[
\text{Equation 3.1: } P(X=r | x=k) = \left( \begin{array}{c} r \\ k \end{array} \right) \times 0.5
\]

where:
X = total number of organisms counted from two samples
P = probability of the total number of organisms being equal to the sum of organisms taken from two samples
x = count from sample 1
k = expected count from sample 2

Lightfoot et al. (1994) provide a table defining a range of acceptable values of a second count from a split sample within the 95% confidence intervals for a number of counts from a first sample. As the count from the first sample increases, the range of values also increases significantly, emphasising the difficulty of precision within microbiological analysis of water.

2.2.1.8 Other parameters of microbiological quality

WHO (1985; 1993) suggests that in addition to the use of indicator bacteria, there are other simple water quality parameters useful in analysing microbiological quality of water. In their guidelines for Drinking-Water Quality, WHO (1993) recommend the use of turbidity, and in chlorinated water supplies, chlorine residuals and pH in monitoring programmes and describe these as the other critical parameters for water quality. These parameters are generally recommended as they may either be expected
to directly control microbiological quality (chlorine residual) or may influence disinfection efficiency (pH and turbidity). Very low chlorine residuals or high turbidity, even in the absence of faecal indicator bacteria, may give cause for concern as they imply reduced protection against contamination and in the case of turbidity, may indicate that sanitary integrity has been compromised.

2.2.1.9 Sampling of water for microbiological analysis

The basis for selection of sample sites and determination of sampling frequency is an important consideration for surveillance programmes and should take into account the population served, type of supply and likely variation in quality (WHO, 1997). In most countries the numbers and frequency of sampling of piped water supplies are based on the population served, with the numbers of samples and sometimes frequency of sampling increasing with increasing populations served (Gray and Gleeson, 1997; WHO, 1993; 1997). The use of population-based approaches is usually justified on the basis that with increasing numbers of users of water supply the risk of infections arising from contamination of the supply and the particular risk of epidemics increases (WHO, 1976).

**Piped water supplies**

Although population-based approaches to calculation of sampling frequency are commonly used, there are shortcomings with such an approach. Maul et al. (1990) and Haas and Heller (1990) note that the presence and numbers of bacteria in samples taken from a distribution system are influenced by the distribution of bacteria in water, which is a function of internal and external factors causing water quality deterioration. They suggest that basing sampling frequency on the basis of population served provides little information about overall risks of contamination and may result in the unnecessary collection of large numbers of samples.

An alternative approach to sample frequency calculation has been described by Geldreich, (1996), which is to base sample numbers and frequency on the volume of water produced or the length of distribution system. Geldreich (1996) notes that both these approaches have significant drawbacks, as a large proportion of the water will not be used for purposes resulting in ingestion, but in other domestic and commercial
activities. Geldreich also notes that problems may be encountered with seasonal variations in consumption as temperatures vary between seasons, which would then logically result in changing frequency of sampling required. The length of distribution system is unlikely to be an adequate criterion given that a number of other factors such as topography, age of pipes and rates of leakage may directly influence water quality (Geldreich, 1996).

Several countries have developed sampling programmes that are designed to reflect both the system characteristics and the population served through water supply zoning (Anon, 1989; Geldreich, 1996; Lloyd et al., 1991; WHO, 1997). Zoning is a means of sub-dividing water supplies into discrete areas served by particular service reservoirs, treatment plants or sources of water to allow stratified sampling programmes to be developed (Anon, 1989; Howard, 2002; Lloyd et al., 1991).

The selection of sites where samples are taken within piped water systems has also been highlighted as critical to ensuring that data generated is representative (Geldreich, 1996). There are a number of approaches to sampling locations involving use of critical fixed sample sites where water quality is deemed most likely to be compromised and random selection of samples sites with the precise sampling varied between each sampling round (Howard, 2002). Geldreich (1996) suggests that, in general, by varying the sample location there is a greater chance of identifying contamination events, as microbiological contamination is generally intermittent in nature and contaminants are often flushed rapidly through distribution systems. This is true even where there is faulty treatment or repeated contamination of primary infrastructure, for instance a service reservoir, occurs. Geldreich suggests that some fixed sampling points may be retained because they represent particular high-risk areas or are at major primary infrastructure nodes (for instance service reservoir outlets), although WHO (1976) recommends that these be minimised.

The timing of sampling is equally important as this may influence the quality of the water. In urban piped water systems, regular sampling is recommended practice, usually expressed as a being every month (WHO, 1993; WHO, 1997). Spreading sample collection throughout the month will provide more representative results in
comparison to clustering of samples on one day when conditions could be atypical (Geldreich, 1996).

Point water sources and household water
Barrett et al. (2000a) and Wright (1986) have shown that in shallow groundwater systems, variation in microbial quality is often seasonal, with marked deterioration noted at the onset of the wet season as faecal contaminants are flushed into the groundwater. They suggest that in many cases sampling should reflect seasonal patterns. The response to rainfall may, however, vary significantly and in some cases be very rapid depending on the nature of the aquifer (Barrett et al., 2000a).

Howard (2002) states that the sampling of water stored within households depends on the objectives of the sampling. For instance, this may be to evaluate the relative importance of source and post-source contamination (Jensen et al., 2002; Moe et al., 1991). In other cases, routine testing of household water may be considered as an important component of ongoing assessment of water handling hygiene. If routine testing of household water is undertaken, Howard (2002) suggests that in general only a sample of households would be visited, with the numbers of households visited and the frequency of sampling being determined by application of the data in decision-making.

2.2.2 Sanitary inspections
Sanitary inspection or sanitary surveys are an inspection methodology that has been consistently promoted by WHO through the Guidelines for Drinking Water Quality, in texts on standard methods and by regulatory bodies (APHA et al., 2000; USEPA, 1999; WHO, 1976; 1985; 1993). Bartram (1996) notes that the origins of sanitary inspection can be traced back to the earliest attempts to monitor and control microbial quality of water and they remain a robust and effective tool for monitoring microbial quality (Gleeson and Gray, 1997; Helmer et al., 1999).

Sanitary inspections are an assessment of the likely hazards and risks to which the water supply is exposed in relation to faecal contamination (Lloyd and Bartram, 1991). Lloyd et al. (1991) describe sanitary inspections as typically employing a
mixture of visual assessment and community/user interview using questionnaires. Lloyd and Bartram (1991) and WHO (1997) note that the questions are usually structured such that when the answer is ‘Yes’ the risk is present and when the answer is ‘No’ the risk is not present. Typically when the answer to a question is ‘Yes’ a score of 1 is allocated and when the answer is ‘No’ a score of zero is allocated. This then allows an overall risk score to be calculated for the water source (Lloyd and Bartram, 1991; Lloyd and Helmer, 1991; WHO, 1997). Evidence from previous work suggests that standardised questionnaires are required to ensure comparability between inspectors (WHO, 1997)

2.2.2.1 Application of sanitary inspection

Lloyd and Bartram (1991) reporting on work in Peru, illustrated the effectiveness of sanitary inspection as a tool in analysing water quality failure, predicting risks of contamination and in informing management decisions. This was further expanded by subsequent work in a number of African and Asian countries (Lloyd and Helmer, 1991).

In some texts, it is suggested that a sanitary inspection should obviate the need for re-sampling (APHA et al., 2000). By contrast, Lloyd and Bartram (1991) suggest that a high level of contamination is unexpected when there is a low overall risk score and as a result, re-sampling should be considered to aid interpretation of the results undertaken, as a sampling error may occurred.

Sanitary inspection as a tool to identify the cause of contamination occurrence

Sanitary inspection has been used as a means of identifying the likely cause of any contamination found and can therefore direct remedial action (Howard, 2002; Lloyd and Bartram, 1991; Lloyd and Helmer, 1991). The overall risk score can be used in conjunction with water quality data to produce a categorisation of the systems in relation to their priority for action, as higher risk scores are expected to result in higher levels of contamination (Lloyd and Helmer, 1991).

Lloyd and Bartram (1991) note that the relationship between water quality and sanitary risk is not strictly linear and as a result, developed a broad categorisation
scheme, shown below in figure 2.2. Within this categorisation, the microbiological results are divided into four categories, with A representing the lowest levels of thermotolerant coliforms and D the highest. The definition of the range of results falling into each category is based on the range of results obtained from the analysis of microbiological quality of water. The categorisation was used to provide a simple mechanism by which to define priorities in improving water supplies (Lloyd and Bartram, 1991).

<table>
<thead>
<tr>
<th>Thermotolerant coliform grade</th>
<th>0</th>
<th>1 – 30</th>
<th>31-70</th>
<th>&gt;70</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Sanitary risk**

<table>
<thead>
<tr>
<th>Priority</th>
<th>No risk, no action</th>
<th>Low risk, low action priority</th>
<th>Intermediate to high risk, higher priority action</th>
<th>Very high risk, urgent action</th>
</tr>
</thead>
</table>

**Figure 2.2: Sanitary risk and water quality categorisation (modified from Lloyd and Bartram, 1991)**

One underlying principle of this categorisation is that all sanitary risks are given equal weight during initial data collection and analysis. Lloyd and Bartram (1991) state that this approach is required because although a particular factor may affect water quality more than others, this could not be quantified. Bartram (1996) further notes that the importance of different risks will be likely to be site specific and that therefore unequal weighting of risks would not have a valid scientific basis when applied more widely.

Most sanitary inspection forms cover a variety of risks, which can grouped into the broad categories (Howard, 2002):
1) Hazard factors – these are potential sources of faeces located so that they may represent a risk to the water supply (an example being a pit latrine)

2) Pathway factors – these are potential routes by which contamination may enter into the water supply (examples being eroded backfill areas of protected springs, or leaking pipes)

3) Indirect factors – these are factors that represent a lack of a control measure to prevent contamination (and therefore increase the likelihood of a hazard or pathway developing), but do not themselves represent either a hazard or a pathway. An example of this is a fence around the water source. The absence of a fence will not lead directly to contamination, but may allow animals or human to gain access to the source and create either a hazard (through defecation) or a pathway (through causing damage to the source or its immediate surroundings).

Howard (2002) suggests that in many cases the presence of sanitary risk factors from each category may be required in order for contamination to result, based on a source-pathway-receptor model that is commonly used to explain contamination (ARGOSS, 2001). There are likely to be exceptions to this general rule, for instance where a particular hazard is the sole cause of the contamination (Lloyd and Bartram, 1991). In such a case, whilst reductions in other risks may be desirable, they may potentially have limited impact on the quality of water (Howard, 2002).

**Sanitary inspection as a predictive tool**

The second application of sanitary inspection is to provide a longer-term perspective on the risk of contamination, which may be of value when water quality sampling programmes are limited (Bartram, 1996; Howard and Luyima, 1999; Lloyd and Bartram, 1991). It is also useful when taking into consideration likely seasonal influences on water quality in many source waters, which may be significant (Barrett et al., 2000a; Wright, 1986). Taking note of the points raised above, however, it would seem logical that the predictive power of sanitary inspection may be dependent on previous analysis of data from representative samples.
Sanitary inspection as a measure of operation and maintenance performance

The third use of sanitary inspection is as a measure of operation and maintenance and of water handling hygiene. Howard and Luyima (1999) note that because sanitary inspections focus on the engineering and environmental measures designed to prevent contamination, they provide a good reflection of operation and maintenance performance, as high risks tend to indicate poor performance by the supply managers.

2.2.3 Chemical quality

The control of chemical quality of drinking water has historically been a far lower priority than microbiological quality (WHO, 1993). This results from the often geographical limit of chemical contaminants, relatively small numbers of people affected in comparison to microbiological quality and because health effects are often debilitating rather than fatal (Regli et al., 1993; WHO, 1993). WHO (1993) note that although mass poisoning of water by chemical contaminants does occur, for many chemicals the concentrations required to induce acute effects would lead consumers to reject such water because of aesthetic reasons, notably taste and colour.

In some cases, however, (notably arsenic, fluoride and nitrate) there is strong evidence of the need to consider at least some chemical parameters in surveillance programmes (WHO, 1997; 2001). Arsenic currently represents probably the single greatest concern about chemical contamination of drinking-water supplies, largely due to the severe problems noted in Bangladesh and West Bengal, India. The scale of the problem of arsenic contamination is most severe in Bangladesh, where shallow groundwater contamination results from deposition of arsenic-containing minerals and compounds in fluvial sediments derived from weathering of arsenic-bearing rocks in the source area (Smedley and Kinneburgh, 2001).

At present, the total population exposed to risks of elevated arsenic in Bangladesh (above the WHO Guideline Value of 0.01mg/l) remains uncertain, but is thought to be somewhere between 35 and 56 million and has been described as the largest recorded poisoning in history (Smith et al., 2000). Arsenic contamination is also being identified as a major health-related drinking water quality threat in many other low- and middle-income countries, (Rasmussen and Andersen, 2001; Smedley and
Kinniburgh, 2001). Problems in Africa remain largely confined to areas of gold mineralisation and where mining activities have released arsenic into surface and ground waters (Smedley, 1996).

Fluoride affects the bone development and in excess leads to dental or in extreme form, skeletal fluorosis. The latter is a painful debilitating disease that causes physical impairment. WHO (1993) has established a Guideline Value of 1.5mg/l for fluoride as being the concentration below which no adverse effect is noted (WHO, 1996a). However, too little fluoride has also be associated with dental caries and other dental ill-health (WHO, 1996a). Bailey et al. (1999) suggest that over 60 million people are affected by fluorosis in India and China and suggest the total global population affected as being 70 million.

Nitrate is also of concern, as it leads to an acute health effect – methaemaglobinaemia or infantile cyanosis (WHO, 1996a). Saywell (1999) notes that there remains uncertainty about the significance of the adverse health effects from nitrate as few low- or middle-income countries include methaemaglobinaemia as a notifiable disease. Raised nitrate is, however, recognised as a significant health risk where levels in groundwater reach extremely high values (Melian et al., 1997). Nitrate is also of concern given that it is conservative in oxidising waters and therefore once in stable groundwater with reasonably high oxygen content, it will not degrade. This may lead to a long-water term resource problem that is expensive and difficult to remediate (ARGOSS, 2001).

The preceding paragraphs have noted the effects of three key chemicals, WHO (1996a) note that there a number of other chemicals whose presence may lead to adverse health effects. WHO (2002) notes that these chemicals may result from pollution from human activity, for instance through agriculture (pesticides), mining (heavy metals, cyanide), small and large-scale industry (many different pollutants including heavy metals, organics), urban runoff (lead, organics) as well as fishing and transport. In addition, a range of chemicals with potentially harmful effects on health may be introduced as a result of chemical treatment (in particular disinfection by-
products, aluminium) or from leaching of contaminants of materials and chemicals used in the treatment of drinking water (WHO, 1993).

In addition to those chemicals with known health effects, there are several other substances that make the water unpalatable, for instance by imparting a colour or odour to the water or by causing staining of clothes and utensils. These include substances such as iron and manganese as well as parameters more accurately described as physio-chemical such as colour. WHO (1997) state that the presence of such substances may lead consumers to reject water supplies of otherwise good quality and may result in increased health risks as more contaminated supplies are used. In addition, other parameters, for instance hardness and corrosivity of water, may cause significant operational difficulties and are therefore of importance for water suppliers, although of less importance for health protection (WHO, 1993).

2.3 Water quantity

In the Guidelines for Drinking-Water Quality, WHO define domestic water as being 'water used for all usual domestic purposes including consumption, bathing and food preparation' (WHO, 1996a; 2002). Although this broad definition provides an overall framework for domestic water usage in the context of quality requirements, it is less useful when considering quantity requirements for domestic supply. Howard and Bartram (2003) note that sub-dividing uses of domestic water is useful in considering the minimum quantities required.

In the 'Drawers of Water' study on water use patterns in East Africa, White et al. (1972) suggested that three types of use could be defined in relation to normal domestic supply:

- Consumption (drinking and cooking)
- Hygiene (including basic needs for personal and domestic cleanliness)
- Amenity use (for instance car washing, lawn watering)

In the process of updating the Drawers of Water study, Thompson et al. (2001) suggest the inclusion of a fourth category of 'productive use', which is of particular relevance to poor households in developing countries. Productive use of water
includes uses such as brewing, animal watering, construction and small-scale horticulture (Fass, 1993).

The first two categories identified by White et al., consumption and hygiene, have direct consequences for health both in relation to physiological needs and in the control of infectious disease. The third and fourth categories, amenity and productive uses, may not directly affect health, although in the latter case productive water may be critical among the urban poor in sustaining livelihoods and avoiding poverty and therefore has considerable indirect influence on human health (Fass, 1993; Thompson et al., 2001).

2.3.1 Consumption requirements

Water is a basic nutrient of the human body and is critical to human life. It supports the digestion of food, adsorption, transportation and use of nutrients and the elimination of toxins and wastes from the body (Kleiner, 1999). Water is therefore a basic requirement for sustaining life. Water is also essential for the preparation of foodstuffs and requirements for food preparation are included in the discussion of consumption requirements.

2.3.2 Basic hydration requirements

The human body requires a minimum amount of water in order to be able sustain life before mild and then severe dehydration occurs. Kleiner (1999) states that health effects have been noted from mild dehydration and that severe dehydration can be fatal. Mild dehydration has been associated with a number of adverse health effects, including increased risks in susceptible groups to urinary stone formation, increased risks of urinary tract cancer and poor oral health. Urinary stone formation is significantly increased when the urine volume excreted is below 1 litre per day and urinary volumes exceeding 2 to 2.5 litres per day can prevent recurrence of stones in previously affected patients (Kleiner, 1999). A recent study in the Adventist community in California noted a strong negative association with intake of water and the risk of fatal coronary heart disease for both men and women (Chan et al., 2002). Some studies have also indicated decreased risks of colonic and breast cancer with increasing fluid intake (Kleiner, 1999).
The definition of the ‘absolute minimum’ quantity of water to sustain hydration remains elusive, as this is dependent on climate, activity level and diet. White et al. (1972) suggested that 2.6 litres of water per day is lost through respiratory loss, insensible perspiration, urination and defecation. In addition, a significant quantity of water would be lost through sweat if hard work were performed. These figures led these authors to suggest that a daily minimum of water required in tropical climates would be between 1.8 and 3.0 litres per person. They note, however, that under extreme conditions of hard work at high temperatures in the sun this figure could rise to as much as 25 litres per day. White et al. (1972) also point out that the proportion of the fluid intake achieved via food would be expected to vary significantly and could provide 100% of the fluid requirement in some cases, notably in pastoralists where milk was the primary food. Kleiner (1999) suggests that based on US National Research Council guidelines in relation to hydration needs resulting from average energy expenditure and environmental exposure, the average male should consume a minimum 2.9 litres per day and the average sedentary female 2.2 litres. Approximately one-third of this fluid is likely to be derived from food. Howard and Bartram (2003) conclude that when hydration needs for moderate activity in high ambient temperatures (which would be typically situation for many of these with least access to water supply) a figure 4.5 litres per capita per day is a reasonable estimate of water needs for hydration.

Pregnant women also require additional fluid replacement to ensure that foetal needs are met, as well as providing for expanding extra-cellular space and amniotic fluid. The US National Research Council suggests an allowance of an extra 30ml per day during pregnancy (Food and Nutrition Board, 1989). Lactating women have additional water requirements, leading to an additional requirement of 750ml to 1 litre per day for the first six months of lactation (Food and Nutrition Board, 1989). As many lactating women in developing countries would also be expected to continue working, a requirement of 5.5 litres per capita per day is a reasonable estimate of hydration needs for the group with least access to water supply (Howard and Bartram, 2003).
2.3.3 Types of fluid

The benefits derived from specific types of fluid consumed are a matter of some debate. For instance, Kleiner suggests that drinking diuretics such as coffee may lead to mild dehydration, although a preliminary study by Grandjean et al. (1999) found no significant difference on hydration status between use of different beverages, but suggest that further research is required.

Chan et al. (2002) demonstrated a statistically significant positive association between consumption of non-alcoholic fluids other than water and increased risk of coronary disease among women consuming over 5 glasses per day compared to those consuming less than 2 glasses per day. The relative risk was 2.47, although the confidence intervals were wide. However, the point estimates of relative risk did not change even when adjusting for more traditional factors for coronary disease. A positive association was also noted in men, although this was not statistically significant.

2.3.4 Water for cooking

In addition to basic requirements for hydration, water is further essential as a medium for cooking food. Defining the requirements for water for cooking is difficult, as this depends on the diet and the role of water in food preparation. However, most cultures have a staple foodstuff, which is usually some form of carbohydrate-rich vegetable or cereal. A minimum requirement for water supplies would therefore also include sufficient water to be able to prepare an adequate quantity of the staple food to provide nutritional benefit for the average family.

It is difficult to be precise about volumes required to prepare staples as this depends on the staple itself. Howard and Bartram (2003) suggest that a reasonable estimate is for 1.6 litres per capita per day for cooking rice, which is the most widely used staple world-wide. In addition, it is not unreasonable to assume that at least a further 0.4 litres would be needed for other food preparation.
Considering basic needs for consumption (including for hydration and in preparation of food), Howard and Bartram (2003) suggest that the volumes of water required for most conditions would be those shown in table 2.2 below.

<table>
<thead>
<tr>
<th></th>
<th>Average conditions</th>
<th>Manual labour in high temperatures</th>
<th>Total needs in pregnancy/lactation</th>
<th>Total need including food preparation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female adults</td>
<td>2.2</td>
<td>4.5</td>
<td>4.8 (pregnancy)</td>
<td>7.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>5.5 (lactation)</td>
<td></td>
</tr>
<tr>
<td>Male adults</td>
<td>2.9</td>
<td>4.5</td>
<td>-</td>
<td>6.5</td>
</tr>
<tr>
<td>Children</td>
<td>1.0</td>
<td>4.5</td>
<td>-</td>
<td>6.5</td>
</tr>
</tbody>
</table>

Table 2.2: Volumes of water required for consumption

2.3.5 Quantity requirement to support hygiene

As noted in section 1.4, the relationship between water quantity and health is complex and availability is likely to be the primary influence. The quantities of water used are influenced by distance, although most studies point only to the influence of gross differences, primarily related to level of service. Reviewing several studies on water use and collection behaviour, Cairncross (1987) suggests that there is a clearly defined graph of water volumes used by households in relation to accessibility, shown in figure 2.2 below.
Once the time taken to collect from the water source exceeds a few minutes (roughly 5 minutes) or the distance of the source is above 100m from the house the quantities of water collected decrease significantly. This graph contains a well-defined ‘plateau’ of consumption that appears to operate within boundaries defined by distances equivalent to 100 to 1000m or 5 to 30 minutes collection time. There is little change in quantity of water collected within these boundaries (Cairncross and Feachem, 1993). Beyond distance of one kilometre or more than 30 minutes total collection time, quantities of water will be expected to further decrease to a bare minimum, which is unlikely to permit any use apart from basic consumption and even this may be under threat (Howard and Bartram, 2003).

![Graph of travel time (in minutes) versus consumption (taken from WELL, 1998)](image)

**Figure 2.2: Graph of travel time (in minutes) versus consumption (taken from WELL, 1998)**

Once water is delivered through at least a single tap on-plot, the quantity of water used increases significantly and further increases only when water is piped into the home and is available through multiple taps. The findings from a study from Jinja, Uganda, shown in table 2.3 below illustrate this point (WELL, 1998). Average consumption of water when it is piped into the home is relatively high (155 l/c/d), but decreases to 50 l/c/d when water is supplied to a yard level. When water is beyond the home, average consumption drops still further to roughly one-third of the average consumption at a yard tap and one-tenth of that for households with water piped into
the home. The available evidence therefore suggests that the volume of water collected is sensitive only to differences in service level.

<table>
<thead>
<tr>
<th>Type of supply</th>
<th>Average consumption (l/c/d)</th>
<th>Service level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traditional sources,</td>
<td>15.8</td>
<td>Communal</td>
</tr>
<tr>
<td>springs or handpumps</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standpost</td>
<td>15.5</td>
<td>Communal</td>
</tr>
<tr>
<td>Yard tap</td>
<td>50</td>
<td>In Compound</td>
</tr>
<tr>
<td>House connection</td>
<td>155</td>
<td>Within house (multiple)</td>
</tr>
</tbody>
</table>

Table 2.3: Average water consumption figures, Jinja, Uganda (WELL, 1998)

Thompson et al. (2001) reporting the findings of recent studies in East Africa suggest that the quantities of water used for bathing (including hand washing) and washing of clothes and dishes is sensitive to service level. Thompson et al. (2001) show that in East Africa, houses using water sources outside the home used an average of 6.6 litres per capita for washing dishes and clothes and 7.3 litres per capita for bathing. By contrast, their results show that houses with a connection to piped water supply use on average 16.3 litres per capita for washing dishes and clothes and 17.4 litres per capita for bathing.

There have also been suggestions that where water is purchased, the cost may also be a limiting factor on the volumes of water used. Cairncross and Kinnear (1992) showed that the cost of water purchased from vendors in Khartoum, Sudan, led to a significant reduction in the quantity of water collected and this compromised hygiene and health. Thompson et al. (2001) note that in East Africa average costs of water for households with a piped water connection in urban areas actually decreased by 20% over the 30 years from the study by White et al. (1972). Thompson et al. (2001) also note that average costs of water used by households without a connection in rural and urban areas increased by 14% and 28% respectively during the same period. At the same
time, water consumption by households with connections to piped water decreased by 50%, while urban and rural households using off-plot water sources actually increased consumption by 60% and 80% respectively. This suggests that overall impact of changes in cost on volumes of water collected may be confounded by other factors. In terms of the influence of cost at a household level, Thompson et al. (2001) indicate that consumption in households using off-plot water supplies was strongly influenced by economic factors, with wealth of the household being the most important factor, followed by the cost per litre of water.

Factors such as supply reliability may also influence quantities of water collected. In India, Zerah (2000) indicates that low-income families are likely to be at greatest risk from poor water supply continuity. As they have more limited resources, they were less able to store large volumes of water at home and this led to the use of smaller volumes of water and impaired hygiene, although this was not quantified.

Howard and Bartram (2003) note that domestic supply should provide adequate water for laundry through some mechanism and this must be considered when improving or constructing water supplies. Thompson et al. (2001) note that in some communities, users of communal supplies may be reluctant to transport sufficient water for laundry and may opt for use of an alternative source. On the basis of research carried out in East Africa, Thompson et al. (2001) conclude that 30% of the population without household connections to a piped water supply use unprotected water sources for laundry. In both rural and urban areas where water is scarce and off-plot, the frequency of laundering may reduce, thus potentially increasing the risks of some infectious diseases (Cairncross and Feachem, 1993; Thompson et al., 2001).

Howard and Bartram (2003) conclude that the available evidence indicates that water quantities used by households is primarily dependent on access as determined by distance and/or time for collection. These differences are seen as functioning at four levels, broadly equivalent to service level, shown in table 2.4 below. It should be noted that for each service level, likely volumes collected may reduce in supplies that are highly intermittent.
<table>
<thead>
<tr>
<th>Service level description</th>
<th>Distance/time measure</th>
<th>Likely quantities collected</th>
<th>Level of health concern</th>
</tr>
</thead>
<tbody>
<tr>
<td>No access</td>
<td>More than 1000m or 30 minutes total collection time</td>
<td>Very low (often less than 5 l/c/d)</td>
<td>Very high as hygiene not assured and consumption needs may be at risk</td>
</tr>
<tr>
<td>Basic access</td>
<td>Between 100 and 1000m (5 to 30 minutes total collection time)</td>
<td>Low and average unlikely to exceed 20 l/c/d</td>
<td>High, emphasis on effective use and water handling hygiene. Not all requirements may be met</td>
</tr>
<tr>
<td>Improved access</td>
<td>On-plot, or at least within 100m or 5 minutes total collection time</td>
<td>Medium, likely to be around 50 l/c/d, higher volumes unlikely as energy/time requirements still significant</td>
<td>Medium to low. Most basic hygiene and consumption needs met. Laundry possible on-site, which increase frequency. Issues of effective use still important</td>
</tr>
<tr>
<td>Optimal access</td>
<td>Water is piped into the home through multiple taps</td>
<td>Varies significantly but likely to be above 100 l/c/d and may be up to 300 l/c/d</td>
<td>Very low. All uses can be met, quality important (supply and in-house), control of consumption may be required</td>
</tr>
</tbody>
</table>

Table 2.4: Service level descriptors of water in relation to hygiene (Howard and Bartram, 2003)

The evidence from the literature reviewed in this section and in section 1.4 shows that quantity is an important indicator for inclusion in a health-based surveillance programme. The evidence indicates that service level provides a good surrogate for quantities of water used. In relation to cost, the evidence available remains limited and contradictory, as does the evidence for relationships between reliability and quantity of water and that further research is required in this area.

2.4 Continuity

WHO (1993; 1997) defines the continuity of water supplies is referred to as the proportion of time (in terms of hours per day and days per year) that water supply is available for use.
2.4.1 Influence of continuity on health

Continuity can be considered as significantly influencing water-related health risks through a number of mechanisms. Rahman et al. (1997) provide evidence to indicate that discontinuous supplies can force the population affected by poor continuity in their main supply to use alternative water sources. This leads to greater risks to health when such sources are of lower quality (WHO, 1997). Zerah (2000) showed in India that discontinuity in supply results in increased storage of water within the home, which leads to increasing risks of contamination when either the household storage container is poorly constructed or personal hygiene is poor (WHO, 1997). Discontinuity may also force people to reduce water consumption, thus leading to deteriorating personal hygiene (WELL, 1998).

In the case of piped water supplies, discontinuity in supply has been linked to increasing susceptibility of microbiological contamination due to back-siphonage into the piped network (Regli et al., 1993). The recharging of the system may result in short term exposure to very elevated numbers of pathogens introduced into the supply through back-siphonage. Outbreaks caused by *Salmonella typhimurium*, cholera, giardia, hepatitis A and *Shigella* spp. have all been linked to ingress of contaminated water into distribution systems (Clark et al., 1993b; Geldreich, 1996; Regli et al., 1993).

The health of low-income families is likely to be at greatest risk from poor water supply continuity (WELL, 1998). For instance, the users of communal taps may have to take the first water supplied after re-charging of the system, even when this may be of the worst quality. Hygiene may also suffer more among poor households, for instance in Delhi Zerah (2000) showed that poor families had limited access to large household storage tanks and it was suggested that this led to the use of smaller volumes of water and impaired hygiene. Rahman et al. (1997) showed that in Pakistan, poor continuity in supply forced low-income household to purchase water from vendors at a much greater cost than the charges levied by the municipal water supplier.
It is likely that the nature of the discontinuity will affect the hardship caused. Whilst regular discontinuity may cause more hardship, this may be mitigated to some extent if the interruption in supply is predictable as this will allow the household to develop coping strategies for water collection. It can be speculated that the greatest problems may be felt when discontinuity is frequent, but very unpredictable.

### 2.4.2 Continuity as a measure of consumer satisfaction

Previous research by Howe and Smith (1984) suggests that continuity in supply has a high value for consumers, who view this as one of the critical measures of the adequacy of their water supply. The value, however, is set against other factors such as the cost of more reliable water. In Colorado, USA, Howe and Smith (1994) showed that in a number of towns, consumers appeared willing to accept lower levels of reliability when this was offset by reductions in the cost of water. In an evaluation of consumer perceptions of different theoretical scenarios of supply reliability, Kwietniewski and Roman (1997) concluded that interruptions of a longer duration that occurred infrequently were preferred by most consumers to those of shorter duration, but greater frequency. The authors concluded that it was therefore important to take account of consumer perception when defining acceptable levels of continuity, particularly in larger supplies.

No comparable studies specific to developing countries have been found in the literature. This may reflect the poor overall access to a piped water supply and the often very poor reliability of current supplies, which is frequently so bad that any improvement in reliability would be seen as significant by the users (Howard, 1996). However, users of piped water supplies in developing countries, like those in developed countries, would be expected to also judge reliability in terms of managing inconvenience and the interaction with costs of water.

### 2.4.3 Temporal, spatial and source-related variation in continuity

Continuity of supply may well reflect significant temporal variations in the source of water and spatial variations within a piped supply. In addition, continuity may be expected to vary between different source types. The possible causes and predictability of continuity are discussed briefly below in order to better inform data
collection strategies. In this discussion, piped water supplies and point supplies are dealt with separately, given the likelihood of different influences on variation in continuity.

2.4.3.1 Piped water supply

The degree of continuity in a piped supply may reflect an insufficient quantity of water at the source (WELL, 1998). For instance, in Ghana, it was noted that in 25 piped water supplies covered in an assessment of water supply performance, 45% suffered rationing of water and frequent discontinuity (WEDC and RCPEH, 1999). In most cases, it was noted that this was due to inadequate treatment works capacity and poor source development. In some cases this was a seasonal occurrence and in others a permanent problem related to insufficient source water capacity.

Although source water quantity was noted as important in Ghana, the numbers of supplies that had discontinuity in the previous 7 days was greater than those simply with a source-related problem (Ince and Howard, 1999). In some cases, the problem may still lie at the production stage of water supply, due to unreliable power supply or under-sized pumping capacity (Howard, 2002). However, in some cases it was noted that problems were caused by inadequate storage of water within distribution systems to cope with peak demands, direct connections to pumping mains with no available storage, leakage and poor pressure maintenance (WEDC and RCPEH, 1999).

The capacity of the source of water in relation to the demand is likely to determine whether interruption in the supply is likely to occur. Where the volume of water available for daily abstraction is lower than the demand placed on the supply, then discontinuity can be expected to result and would be indicative of under-design. Such discontinuity may be year-round or more commonly influenced by seasonal variations in flows and water tables. WHO (1997) also notes that inadequate system storage or excessive leakage may result in discontinuity and that this may be less predictable than source inadequacies (WELL, 1998).

The frequency of data collection on continuity in piped water supply would seem to be primarily determined by the predictability of the discontinuity. Where
discontinuity is unpredictable at local levels, more frequent data collection would be expected to be required to determine the scale of the problem. Where discontinuity is predictable (for instance where water is rationed) data collection may be expected to be far less frequent and undertaken in the context of specific assessments of areas or supplies particularly affected.

### 2.4.3.2 Other sources of water

Price (1985) notes that continuity in point water supplies will tend to reflect seasonal water shortages and would be typical of development of seasonal springs or where boreholes have been sunk into perched aquifers. Seasonal discontinuity in such sources may indicate poor planning and design of these sources, but could also be caused by the sinking of other boreholes or wells which cause seasonal drops in the groundwater level (Brassington, 1988; Price, 1985).

Boreholes and wells with handpumps can be further affected by breakdowns and discontinuity and this is reflected as a 'downtime' - the amount of time taken before operation is restored (Taylor, 1993). Where households collect rainwater as their primary source of water, discontinuity will be expected to reflect seasonal or annual variations in the amount of precipitation (Gould and Nissen-Petersen, 1999). Gould and Nissen-Petersen (1999) provide design criteria and examples of the impact of seasonality in rainfall on the size of storage tanks and catchment areas required for tropical countries and temperate climates. Bartram (1996) and Lloyd and Helmer (1991) indicate that collecting data on continuity in supply of point sources (including rainwater) provides useful information regarding whether such supplies are adequate.

Where households must rely on vendors, discontinuity in supply may result from either vendors not visiting the area or having restricted volumes of water for sale (Cairncross and Kinnear, 1992). For instance, in Lima it was noted that poor households living in shanty towns suffered from poor continuity in supply because vendors were often unable to collect water from hydrants due to rationing within the piped water system (Lloyd et al., 1991).
As continuity of supply from point sources would be expected to broadly follow seasonal patterns, this information is likely to be well known to the users. In this case, data collection may only need to be relatively infrequent and obtained through user interviews. Where downtime affects the continuity of supply, more frequent data may need to be collected, although again this would seem to be feasible through periodic assessments of functionality.

2.5 Cost

WELL (1998) note that in urban areas most of the water supply available is provided by utilities operating a piped water system or by vendors and entails a monetary cost to consumers. This is in contrast to rural areas where donation of labour has generally been the cost accrued by households and communities (World Bank, 1993). In a study of water prices worldwide, Flood (1997) concluded that the cost of water services is significantly higher in Africa than other developing and transitional regions and approaches prices seen in the developed world.

The cost of water exerts a significant influence on the decision households make in terms of selecting the level and type of supply they utilise (Lewin et al., 1996, Lloyd et al., 1991). Fass (1993) notes that in Haiti, because water was a major component of household expenditure, increasing costs of water may have a significant adverse affect on household income and increase vulnerability. In a study in Khartoum, Sudan, Cairncross and Kinnear (1992) noted that the high cost of water was likely to lead to reductions in expenditure on on food, leading to increasing under-nourishment and vulnerability to infectious disease.

High costs of good quality water may lead to the use of other, more contaminated, water supplies and increasing costs of water have been noted as being related to reducing the amount of water used for personal hygiene (Cairncross and Feachem, 1993). Such findings are not, however, universal. For instance, a study in Jinja, Uganda, indicated that volumes of water collected by households using non-piped communal sources were only marginally higher than those using communal taps, despite the former being primarily free at the point of collection (Morris and Parry-Jones, 1999).
2.5.1 Social tariffs and cost-recovery

In many countries there is social provision of water supplies through communal facilities. Whilst public taps may be available to all those households lacking a direct connection of their own, whether this water must be purchased and if so at what cost, is reported to vary. For instance, in some countries water at such facilities is supplied free of charge (McPhail, 1993).

Rabemanamobla (1997) and Thema (1997) note that in many African towns, charges are levied at public taps to ensure that costs are recovered at these facilities. There has been a long tradition of charging for water from public taps in Uganda (Onek, 1997; White et al., 1972). In cases where payment is required, utilities may apply a tariff that is lower than that charged to households with a direct connection (Kayaga, 1997; Morris and Parry-Jones, 1999). Howard (2001) notes that in Uganda the tariff charged by the utility may not reflect the actual cost paid by households collecting water, which is often higher than that paid by consumers with a direct connection. This higher cost reflects the need to take into account additional expenditures related to employment of a caretaker for the facility and in some cases reflects minimum tariffs levied by utilities (Howard, 2001).

In many urban areas of developing countries, on-selling by households with a domestic connection the piped water supply is significant (Howard, 2001; Morris and Parry-Jones, 1999; Tatiets and Rodriguez, 2001). The price paid by poor households per unit of water from 'on-sellers' is often greatly in excess of that paid by higher-income households enjoying a much better level of service (Briscoe, 1996; Franceys, 1997; Hardoy and Satterthwaite, 1989; Stephens, 1995a). Cairncross (1990b) notes that where vendors are used, costs may increase even further.

The literature points to the value of cost as an important indicator for surveillance programmes, but suggests that data on the actual costs paid by the urban poor is important rather than placing sole reliance on published tariffs. These data can then be assessed to investigate whether cost has an impact on water use and can be differentiated by service level in order to determine whether the urban poor are
suffering particular disadvantage. In addition to recurrent expenditure, the literature suggests that evaluation of data regarding capital investment costs for securing a water connection, and the role of both capital investment cost and tariff structure in relation to potential uptake by the urban poor, would be of value.

2.6 Access and use of water sources

Access to water supplies is usually described as the ease by which water may be collected and, therefore, at one level refers to the distance to the source or the time taken to collect water, which may incorporate waiting times at a communal source (Bartram, 1996; WHO, 1997).

WELL (1998) suggests that there are three broad levels of service that can be defined when measuring access:

1. Communal sources external to the home;
2. Water supplied to a single tap on the plot;
3. Water supplied within the home through multiple taps.

The first may be differentiated by source type, as these may provide water of different costs, reliability and quality and therefore risk to the users health (Lloyd et al., 1991). Furthermore, the differences in source types may provide further information regarding the nature of the socio-economic status of different communities (Satterthwaite, 1997). In addition, the use of water is also noted as important for surveillance programmes (Howard et al., 2002a).

2.6.1 Water use

Accessibility of water sources can be expected to influence the selection of water sources used by households. Ahmed et al. (1998) and Howard et al. (2002a) show that when water is supplied off-plot, then the use of multiple sources of water is common, particularly where alternatives are easily available. Almedom and Odhiano (1994) and Ahmed et al. (1998) note that where multiple sources of water are used, the purpose to which water is put may vary between different sources. Different sources may be used for different purposes, based on household judgements as to the acceptability of
the source for each use (Madanat and Humplick, 1993). The differential use of water from different sources has been called a 'rationality factor' (Almedom and Odhiano, 1994). Howard et al. (2002a) note that use must be understood when implementing water quality surveillance programmes to ensure that sources included are those used for consumption, as well as providing a more realistic assessment of water supply adequacy.

Although the studies noted above showed that rationality in water use operates, it cannot be assumed that differentiation in use by source will always be found. For instance, studies in Bangladesh noted a differentiation in use between protected sources (in this case tubewells with handpumps and taps) and surface water sources, but that there was no differentiation in use between the protected source types (Ahmed and Hossain, 1997; Ahmed et al., 1998).

The literature shows that use of water from multiple sources is an important factor to investigate in surveillance programmes. Collection of this data may be carried out through assessments of water usage behaviour (Howard et al., 2002a).

**2.6.2 Estimates of ‘coverage’**

WHO (1993) defines coverage as the number of people with access to a recognisable, usually public, water supply and therefore is a measure, in part, of access. Many measures of coverage, however, incorporate some qualification regarding type, adequacy or quality of the supply, for instance the UNDP (1999) and the World Bank (1999) refer to access to ‘safe’ drinking water.

Several authors (Bartram, 1996; Middleton, 1999; World Resources Institute, 1996) have commented upon the problems with defining coverage and the limited value of such measures for comparison between countries, given the very different definitions of what constitutes ‘coverage’. The use of coverage as a measure of water supply adequacy has been criticised by many commentators as discussed by Bartram (1996).

Bartram (1996) notes in particular that coverage represents a simplistic measure of sector performance based purely on the presence of infrastructure without paying
regard to the reliability, functional status, quality or use of that water supply. For instance, Taylor (1993) notes that at any one time 20-30% of water supplies in Zimbabwe are non-functional but their presence is still taken to represent the achievement of access for the communities they serve. Equally, studies in urban India showed that the degree of unreliability in piped water supplies illustrated a significant difference between reported coverage and the users’ experience of the supply (Zerah, 2000). Both these authors suggest that the use of a coverage measure in isolation of other measures may give a distorted picture of water sector status.

In their Global Water Supply and Sanitation Assessment 2000 Report, WHO and UNICEF (2000) referred to populations who had access to an improved water supply within one kilometre of their house. Precise definitions were provided about the water supplies deemed to be ‘improved’ and those that were ‘unimproved’. Reliability was also incorporated by a stipulation that an improved piped source was one that met demands 50% of the time and that boreholes were functional for 70% of the time. The authors of the report suggest that as the data for the Global Assessment were derived from households during Multiple Indicator Cluster Surveys and Demographic and Health Surveys they provided comparable data that is representative of user experience (WHO and UNICEF, 2000).

One drawback of the data from the Global Assessment is that most surveys only report on the principal water source used by households, which may lead bias where multiple source use is common. Furthermore, the lack of evidence relating to quality of improved sources allows little differentiation to be made between different source types. Thus whilst access to some form of improved supply can be shown, evidence of the health risks derived from poor water supply remains elusive.

As concluded by Bartram (1996), there appears to be little justification in retaining a separate indicator relating to ‘coverage’ as this is difficult to define and would most logically be replaced by an access/use indicator. Data from other indicators (quality, cost and continuity) can then provide some indication of the quality and adequacy of the water supplies used by the population.
2.7 Unaccounted-for-water

In many circumstances the high level of water loss within a water supply is a direct contributing factor to the inability of water suppliers to provide water to the population (Kalbermatten and Middleton, 1999). Unaccounted-for-water (UfW) may therefore have some relevance to surveillance programmes, but does not appear in the WHO list of key indicators for surveillance (WHO, 1997).

One of the problems in measuring UfW is the variability in its definition. In an extensive review, Xie et al. (1993) note that there appears to be little systematic definition of UfW and found at least three different definitions of UfW within the internal documents of the World Bank. Different definitions may be required depending on whether metered or unmetered systems are in place (Chowdury et al., 1999). In their review, Xie et al. (1993) note that many approaches to UfW focus on the difference between water produced and that for which revenue is recovered, usually taking into account residual non-revenue water such as fire-fighting water.

Chowdhury et al. (1999) show that leakage and other physical losses frequently constitutes the principal component of UfW. In terms of health consequences, physical losses are important as they may lead to back-siphonage in piped supplies and may reduce water available for hygiene (Clarke et al., 1993a; Geldreich, 1996; Regli et al., 1993). Levels of leakage may also affect continuity in the supply, thus causing further health concerns (WELL, 1998). The literature suggest that collection of data on leakage may be important and WHO (1997) suggests that some estimate of leakage can be an important function of water supply surveillance.

2.8 Vulnerability and zoning as an assessment tool

The influence of poverty on both health and water supply was discussed in Section 1.2 and showed that low-income households often have least access to water supplies and as a consequence bear a high burden of water-related disease. Previous work in surveillance programmes in developing countries has also indicated the need to target activities on the poor (Lloyd et al., 1991). Given the strong link between poverty, health and water supply, some measure of poverty should logically form part of the
water supply adequacy assessment process. Poverty would not, however, be used as an indicator per se, but rather as a tool for directing activities into high-priority communities and as an additional measure to assess vulnerability.

Jarman, (1984) and Stephens (1995b) describe the use of measures of poverty in relation to adverse health outcomes and vulnerability in both developed and developing countries. There are numerous ways in which poverty may be measured, using both qualitative and quantitative techniques. McGranahan et al. (1997) note that qualitative data are often difficult to generalise to other areas and require more time and resources in data collection, whilst quantitative techniques provide results that are more easily generalised, but may not provide the same degree of understanding poverty and coping strategies.

For surveillance programmes, the primary use of poverty will be to direct activities to communities that are most vulnerable and would not be expected to develop detailed assessments of coping strategies. Therefore, the primary need is for a system that allows rapid categorisation of communities, which could lead to a form of zoning or characterisation of the urban population into smaller groups of similar nature. During work in Lima, Peru, an attempt was made to develop such a methodology based on a qualitative assessment of socio-economic conditions (Lloyd et al., 1991). In this approach, surveillance staff visited an area to verify street arrangement and housing against whatever maps were available and visited one dwelling per block of housing units to determine the means of provision of drinking water. On the basis of the results obtained the urban area was divided with respect to the dominant means of water supply provision into more-or-less homogenous areas of very variable size, which typically bore little relationship to administrative boundaries (Jamie Bartram, personal communication).

The project found that this technique provided a means by which surveillance programmes could identify small, and often 'informal', settlements usually of very high density, low service provision and perceived high vulnerability. This information was then used in directing subsequent data collection by the surveillance programme. This approach, however, did not cover the entire city. It is also unclear whether the
selection of the dwellings was based on any form of statistically valid form of surveying. Nonetheless, this approach showed that it was feasible for surveillance programmes to take vulnerability and poverty into account.

Developing a zoning methodology to apply across a whole urban area represents one of the key research issues in this thesis. For such an assessment to be effective, it should be able to provide a reliable estimate of vulnerability (which may then require verification using health data) and be possible to construct, preferably using existing data and using primarily desk-based methods with subsequent field validation. As the key point of zoning is to provide a rapid assessment, it should also be robust and provide a reasonable reflection of vulnerability without requiring frequent updating.

2.9 Selected indicators

The previous sections have reviewed the available indicators of water supply of relevance to water-related health risks. The following conclusions can be drawn about the value of these indicators and their means of measurement. Testing the robustness and ease of measurement of these indicators in Uganda was an important component of this study.

**Water quality:** a focus on microbiological quality is justified from the literature and this should encompass a range of techniques including analysis of indicator bacteria (primarily thermotolerant coliforms), turbidity, and chlorine residual and pH where water supplies are chlorinated. These should be supported by sanitary inspection. Regular and frequent monitoring appears justified for microbiological quality given temporal and spatial variations. Chemical quality parameters are a lower priority and determined on a case by case basis depending on the identified health risks.

**Water quantity:** the principal focus of interest is that of quantity of water used, rather than quantity available and there is a value in estimating differences in water quantity collected in relation to costs of water. In terms of distance, the literature suggests that service level and continuity provide more easily measured surrogates.
Continuity in supply: this is of importance as it may lead to deteriorating microbiological quality due to contamination of water supplies or use of supplies that are more reliable, but of lower quality. The consequences of interruption in supply affect low-income households to a greater extent and therefore continuity provides a means of assessing social disadvantage and user satisfaction with the service.

Cost of water: this may influence the selection of water source and therefore risk from consuming contaminated drinking water. It is also clear that in many situations the poor pay significantly more for water supply. Data on costs are therefore required, but should be based on estimates of actual prices paid rather than solely on utility tariffs.

Access and use: the estimation of access remains important as it provides an indication of availability (important for other data to be collected), but should be augmented by estimates of actual levels of use.

Leakage: this is of principal influence in relation to overall system assessments when looking at adequacy and in relation to water quality and would be only qualitative estimates.

Zoning and poverty: measures of poverty should be included within the surveillance programme design in order to target those areas that are most vulnerable to water-related disease. The use of zoning of urban areas will be tested as a tool for incorporating these data within the surveillance programme design.
3.1 Introduction

This chapter presents the materials and methods used in collecting and analysing the data from the field study in Uganda. The chapter is split into a series of sections, which follow the same order as the presentation of results. These sections are:

3.2 describes the assessment of institutional arrangements for the surveillance programme in Uganda;
3.3 describes the criteria used in the selection of the study areas;
3.4 describes how data on the socio-economic status of households were collected and analysed and describes the zoning methodology employed;
3.5 describes how water quality and sanitary inspection data were collected and analysed for water sources and water stored in homes, and the development of software for the management of water quality and sanitary inspection data;
3.6 describes how data on access and use of water sources by the population in the study sites were collected and analysed;

3.7 describes how data on the other indicators of water supply adequacy (discontinuity, cost, leakage and quantity) were collected and analysed; and,

3.8 describes the statistical tests employed in data analysis.

The project in Uganda developed through a series of stages, as shown in figure 3.1 below.

**Figure 3.1: Project development in Uganda**

### 3.2 Project Institutional Arrangements

The first activity in the fieldwork stage was to identify the institutions that would be
involved in the project in Uganda and to outline their respective roles and responsibilities with regard to water quality. From the outset it was decided that the project would focus on developing the public health oversight surveillance function rather than the quality control procedures used by water suppliers. The institutional assessment was undertaken through a review of policy documents and legislation to identify Government (national and local) departments that had some responsibility in relation to water supply or public health. Uganda has a decentralised system of Government. National Government departments are required to provide the policy and legislative framework and provide technical guidance, but provision of all services and implementation of programmes lies with local Government. Therefore, the institutional analysis also identified the different roles expected of local and national Government departments, in particular relating to responsibilities for developing policy and for implementation. The process followed is illustrated in figure 3.2.

Information was also collected regarding the donor organisations, UN bodies and NGOs that had some interest in the water and public health sectors. This was done through review of existing projects and programmes of support to national and local Government by means of round-table discussions with Ugandan professionals in the water and public health sectors and a review of documents. A series of meetings was arranged with the Government departments, donors, UN bodies and NGOs to clarify which activities fell under their jurisdiction or received their support. These meetings were also held to find out whether particular agencies and departments had special areas of interest. In the case of the donors, UN bodies and NGOs this was used to identify which had active programmes or interest in urban water supply.

The information collected allowed the identification of a national lead agency - the Ministry of Health - and the identification of appropriate bodies for implementation within each urban area. In order to maximise the sharing of information and to encourage networking, regular round-table meetings were held throughout the project to which representatives from the water sector and the donor, UN and NGO sectors were also invited.
The information on the institutional arrangements was recorded in project documents and key staff from each institution were identified. The process followed is summarised in figure 3.2 below, which shows the allocation of responsibilities that was agreed under the surveillance programme in relation to mandates within the policy and service provision arrangements in Uganda.
Review of available policy and legislative documents

Identification of roles and responsibilities for water and public health in Government

Identification of other organisations with an interest in water and public health

Donors and UN bodies: DFID, DANIDA, UNICEF, WHO, World Bank

NGOs: Save the Children Fund, WaterAid, Plan International Concern

Ministry of Health responsible for health policy and prevention of epidemics

Local government responsible for ensuring safe water supply in urban areas

National Water & Sewerage Corporation responsible for piped water in designated towns

Directorate of Water Development responsible for overall water sector policy, planning and regulation

Participation in training and ongoing information exchange

National lead agency for surveillance

Implementation of surveillance in urban areas

Regular consultation and feedback on results and progress

Figure 3.2: Institutional assessment and identified roles and responsibilities
3.3 Selection of study areas

It was not feasible, with the available resources, to have initiated surveillance activities in all urban areas and as the research was concerned with methodological development, it was felt that a sample of urban areas should be selected. It was considered that the lessons learnt from these towns would help inform how surveillance programmes could be most effectively implemented. The selection of field sites was based on a set of criteria as follows:

- they were classified as urban under Uganda law;
- the sample of towns should be representative of medium and large urban areas to capture a range of experience, with at least one representative smaller town included;
- the towns selected should be representative of the different cultural and social environments in the country to account for regional differences;
- the towns selected should reflect administrative arrangements of water supply provision in urban areas with a sample of towns with water supplied by the National Water and Sewerage Corporation (a national parastatal organisation) and a sample where piped water was supplied by Municipal councils.

A review of recent census data was made to assess the range of urban settlements suitable for inclusion in study. Selection of urban areas was made through round-table discussions with representatives of the Ministry of Health, Ministry of Local Government, Directorate of Water Development and selected donor and UN agencies, including DFID (UK), UNICEF and WHO.

A total of ten towns were included in the study and their locations within Uganda are shown in figure 3.3 below.
Figure 3.3: Map of Uganda showing the study sites
The towns included four in the central belt of the country, three from the southwest and three from the east. It had been hoped to include at least one town from the north or far west of the country, but the security situation prevented this from being realised. Detailed descriptions of each site are provided in Annex 1. Table 3.1 below summarises the key details of the towns selected, including their location within Uganda, size and piped water administration. The size categories are arbitrary classifications that reflected the views of the participants in the round-table discussions.

<table>
<thead>
<tr>
<th>Town</th>
<th>Location within Uganda</th>
<th>Size of town</th>
<th>Piped water supply administration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entebbe</td>
<td>Central</td>
<td>Medium</td>
<td>NW&amp;SC</td>
</tr>
<tr>
<td>Jinja</td>
<td>Central</td>
<td>Large</td>
<td>NW&amp;SC</td>
</tr>
<tr>
<td>Kabale</td>
<td>Southwest</td>
<td>Medium</td>
<td>Local Government</td>
</tr>
<tr>
<td>Kampala</td>
<td>Central</td>
<td>Large</td>
<td>NW&amp;SC</td>
</tr>
<tr>
<td>Masaka</td>
<td>Southwest</td>
<td>Medium</td>
<td>NW&amp;SC</td>
</tr>
<tr>
<td>Mbale</td>
<td>East</td>
<td>Large</td>
<td>NW&amp;SC</td>
</tr>
<tr>
<td>Mbarara</td>
<td>Southwest</td>
<td>Medium</td>
<td>NW&amp;SC</td>
</tr>
<tr>
<td>Mukono</td>
<td>Central</td>
<td>Small</td>
<td>None</td>
</tr>
<tr>
<td>Soroti</td>
<td>East</td>
<td>Medium</td>
<td>Local Government</td>
</tr>
<tr>
<td>Tororo</td>
<td>East</td>
<td>Medium</td>
<td>NW&amp;SC</td>
</tr>
</tbody>
</table>

Table 3.1: Summary details of the towns selected

For each town, the population at the time of inclusion in the study was estimated using equation 3.1 (Pollard et al., 1974):

Equation 3.1: \( P_n = P_0 (1 + r)^n \)

Where
- \( P_n \) = Population in year when the town was included in the surveillance programme
- \( P_0 \) = Initial population (in the case of Uganda 1991)
- \( r \) = growth rate
- \( n \) = number of years between Po and Pn
This was done because the most recent census data dated from 1991 (Government of Uganda, 1994). The estimated population was based on the urban growth rate for Uganda of 4.76% reported by the World Resources Institute (1996) rather than the national or local growth rates, as these were aggregated for both rural and urban populations.

The implementation of field activities was to be undertaken through local Government in line with Uganda policy and legislation and therefore the administrative divisions used by local Government in planning exercises were defined for each town.

3.4 Socio-economic status and zoning of urban areas

3.4.1 Socio-economic index

Socio-economic status within urban areas was determined by means of an socio-economic index. This approach has been applied in relation to health outcomes in the UK and developing countries and as a result the use of socio-economic indices to define relative poverty has become an internationally accepted methodology. (Jarman, 1984; Stephens, 1995b).

The first stage was to define a range of possible suitable variables to be included in the index. This was done with advice from consultants at the London School of Hygiene and Tropical Medicine. Following initial identification of the variables, the development of the index followed a process of discussion with sector professionals in Uganda, primarily in Kampala where differentials in socio-economic status were most pronounced. An initial set of ten variables was selected by the author and two colleagues based on the information available from the 1991 census. These were:

- Occupation
- Educational attainment
- Average household size
- Main source of household livelihood
- Persons per room
- Roof material type
• Floor material type
• Wall material type
• Household cottage industry activity
• Housing unit type

Following this selection, a series of workshops were held with different professional groups to discuss and review the sensitivity of each variable in relation to socio-economic status. This process, based on a modified ‘Delphi’ technique has been used previously when establishing an index of social deprivation and links to vulnerability to ill-health (Stephens et al., 1997).

The first group of professionals selected was a small group of public health professionals from the Ministry of Health who had a good understanding of the links between poverty and health. The second group was a selection of health assistants, health inspectors and medical staff from Kampala City Council. A final group was a set of professionals from Universities and donor agencies who were asked to comment on the index finally developed, although this latter group provided little feedback.

A shorter list of six variables was identified during these consultations and these were used in the index, as they were concluded to be the most sensitive to socio-economic status within a city or town. These were:
• Roof material type
• Floor material type
• Persons per room
• Educational attainment
• Main source of household livelihood
• Average household size

The remaining four were discarded as they were felt not to be sensitive to socio-economic status or were ambiguous.
The variables selected were then weighted on the basis of their perceived sensitivity to socio-economic status. The higher the weighting score, the greater the sensitivity of the proxy to socio-economic status, with a weight of 1 indicating relatively low sensitivity. The groups were asked to rank the variables in relation to their sensitivity to socio-economic status and discuss the strength of difference between variables in terms of their sensitivity. For each variable, there were a number of 'conditions', for instance different types of roof material. These were allocated scores to reflect socio-economic status.

A score for each Parish was then calculated for each variable by multiplying the percentage of households in Parishes for each condition by the condition score. These were then added to provide a cumulative score for the variable for each Parish. The total percentage of households was calculated. The cumulative score was then transformed into a weighted score by dividing the cumulative score by the total percentage.

The average weighted score and standard deviation of the weighted score for all Parishes in each town was then calculated. A standardised score was finally calculated for each variable in each Parish using equation 3.2:

\[ \frac{X - \bar{X}}{\sigma} \]

Where:
- \( X \) = weighted score for each variable for the Parish
- \( \bar{X} \) = average weighted score for each variable for all Parishes in each town
- \( \sigma \) = standard deviation of weighted scores for each variable for all Parishes in each town

The scores for each variable for each Parish were then added up to provide a final index score. The index was validated by asking field staff who had commented on the initial development of the index to review whether the final categorisation of Parishes within their Division was accurate.
3.4.2 Urban zoning

The urban areas were divided into discrete zones taking into account socio-economic level, population density and water source use patterns. These were subsequently ranked in terms of their priority for surveillance. The zones were constructed by developing an integrated index incorporating several factors:

- Socio-economic status
- Population density
- Water availability and use (the ‘water economy’)

Socio-economic status was defined using the approach outlined in Section 3.4.1 above and the Parishes classified as low, medium and high income. Population density was calculated by taking the estimated population for each Parish and dividing this by the area of each Parish. The water economy measure was composed of assessments of the level of direct connection, the availability of different source types and the use of different sources both in terms of the type of source used and in terms of relative priority for consumption of water. Categories of water economy were defined as shown in table 3.2.

<table>
<thead>
<tr>
<th>Category</th>
<th>Inventory</th>
<th>Water usage study</th>
<th>Connection review</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mainly using piped water</td>
<td>No point sources</td>
<td>Over 50% households use taps</td>
<td>Over 30% of households connected</td>
</tr>
<tr>
<td>Mixed use of piped water and point sources</td>
<td>Point sources and taps recorded</td>
<td>Less than 50% of households use taps</td>
<td>Less than 30% of households connected</td>
</tr>
<tr>
<td>Mainly using point sources</td>
<td>Less than two taps recorded</td>
<td>Less than 20% households use taps</td>
<td>Less than 10% of households connected</td>
</tr>
</tbody>
</table>

Table 3.2: Categories for water economy used in zoning
The zoning process essentially worked on three levels of stratification with socio-economic status defining the first level of stratification, population density the second level and water economy the third level. Thus, socio-economic status is used to broadly define different areas into high, medium and low income. The population density was then used to categorise different low-income areas into high, medium and low density. Similar low-income population areas were also categorised by their water economy, in order to identify those areas likely to be at greatest risk, usually related to the level of use of non-piped or poorly protected point sources.

3.5 Water quality

The water quality of protected point sources, piped water and households was analysed in the study. The principal focus of water quality analysis was on the critical parameters identified by WHO (1993) to describe microbiological quality and sanitary inspection. The parameters analysed at point sources were thermotolerant coliforms and turbidity, and in piped supplies and household water pH and chlorine residuals were also analysed.

3.5.1 Microbiological parameters

Analysis was undertaken using the Oxfam-DelAgua portable testing kit (RCPEH, University of Surrey). Some limited confirmatory tests were also performed at the Public Health and Environmental Engineering laboratory, Department of Civil Engineering, Makerere University, Kampala.

Staff using the kits were provided with training in the use of the kits and surveillance techniques through a 5-day training event. Follow-up training was also provided through a series of field visits by the author and colleagues from the Ministry of Health and by holding regular 2-day refresher courses. Each kit was also provided with a manual describing how to use and maintain the equipment.

Analytical quality control was practised by ensuring that field staff periodically undertook duplicate tests on the first and last samples taken on one day’s sampling. This was compared to a predicted range noted in papers prepared by the UK Public Health Laboratory Service (Lightfoot et al., 1994). Where significant problems were
noted, follow-up work was undertaken with field staff to identify the problems and rectify these through additional training.

In addition a more general quality assurance process was adopted by ensuring that all staff trained were able to use the equipment properly through support supervision visits. An aseptic technique evaluation form was developed as shown in Annex 2. For each question, the field staff obtained a score depending on the number of times the technique was performed correctly. The proportion of the number of times each technique had been performed properly was calculated to provide a final score expressed as a percentage. Where staff fell below 95% compliance, additional training was provided.

Samples of water were collected and processed on-site using the methods described in the test kit manual (RCPEH, 2000). Prior to collecting a sample, the sampling cup and filtration unit were sterilised through burning of methanol which inactivates bacteria through a combination of direct heat and the release of formaldehyde gas when burnt in restricted oxygen (RCPEH, 2000). The unit was left for five minutes to allow for full sterilisation. In most cases, the sample points were not sterilised before sampling, as it was desired to obtain the quality of water as collected by users. In approximately 10% of samples taken from taps and boreholes, duplicate samples were taken and the outlet was sterilised by flaming for the second sample to assess whether contamination derived from the water supply or from poor hygiene at the sampling point.

In line with recommendations regarding sampling of water supplies, taps were left to run for 2 minutes and water from boreholes was pumped for 2 minutes prior to sampling (WHO, 1997). The sample cup was rinsed three times with the water to be analysed before taking the sample to remove any residual traces of methanol that might inhibit the growth of bacteria. A 500ml sample of water was taken at each sampling point. Volumes analysed were, by preference, 100ml as the standard method reporting for results of thermotolerant analysis is the number of colony forming units per 100ml volume (Anon, 2000). Where the source water was turbid or previous results had indicated very high levels of contamination, sample volumes were reduced...
to 50ml and in some extreme examples to 10ml. Dilutions were not performed in the field. Where smaller sample volumes were used, the sample volume and colonies identified were recorded and the equivalent number of colonies forming units per 100ml volume calculated. For chlorinated water supplies, sodium thiosulphate was not added because the samples were analysed on site and therefore no interference was expected (Bartram and Ballance, 1996).

The isolation and enumeration of thermotolerant coliforms was carried out using membrane filtration (Anon, 1982). The water was passed through a Gelman 0.45μm nitro-cellulose filter and the filter placed on a Gelman absorbent pad pre-soaked in membrane lauryl sulphate broth in an aluminium petri dish (Oxoid, Basingstoke, UK). The prepared membranes were pre-incubated at ambient temperatures (25-30°C) for a minimum of one hour and maximum of four hours to enhance the recovery of target organisms (RCPEH, 2000; WHO, 1997). Incubation of the sample was for a minimum of 14 hours, as recommended in the Oxfam-DelAgua kit manual but more typically was for 16 to 18 hours (RCPEH, 2000). After incubation, all yellow colonies between 1mm and 3mm diameter found on the filters were counted as thermotolerant coliforms.

### 3.5.2 Other parameters

Turbidity was analysed using turbidity tubes calibrated against both the nephelometric turbidity unit and Jackson turbidity unit scales (RCPEH, 2000). In this method, a black circle is marked on the base of the bottom tube and water added until it can no longer been seen. The turbidity was then read from the graduations on the tube. Where this fell between two graduations, an estimate was made. The tubes had a range of 5 to 2000TU, results at extreme levels were recorded as <5 or >2000 as appropriate. The manufacture of the tubes within the Oxfam-DelAgua kit involved measures of accuracy and precision (RCPEH, 2000) and no further tests were done to check precision, although during training there were exercises to ensure reasonable comparability of readings obtained between staff.

The appearance of water was assessed for all samples and categorised as clear, unclear or coloured. Taste was not included because it was felt inappropriate to ask
staff to taste (and therefore potentially ingest) water of unknown microbiological quality. However, for both taste and odour, allowance was made for field staff to question community members about the taste and to comment on this on the report sheets.

Free and total chlorine residuals were measured with a simple comparator using DPD tablets following the method prescribed by the suppliers (Palintest, Gateshead, UK). Free chlorine was analysed first using a DPD1 tablet that was added to sample water in the chamber and dissolved. The reading is taken immediately the tablet was dissolved and obtained by matching the colour in the test chamber with reference colours on the comparator. Total chlorine was measured by adding a DPD3 tablet after a DPD1 tablet has been added and a reading obtained after the dissolved tablet has been left for 10 minutes.

The pH of the water was also analysed in the comparator using a Phenol Red tablet following the method prescribed by the suppliers. The tablet is added to a fresh sample in the chamber, shaken to dissolve the tablet and an immediate reading taken matched against the reference colours on the comparator. No tests were for accuracy and precision were undertaken.

On each day of sampling results were recorded on the form shown in Annex 3. This form included details on time of sampling and the sample volumes used for thermotolerant coliform analysis, which allowed a check to be made on reported microbiological results. The data was put into the Sanman database (DataProcessing, Aberdare). This is described in more detail in section 3.5.5.

3.5.3 Sampling programme design

The water quality component of surveillance requires frequent data collection to take into account significant temporal and spatial variations. Therefore representative sampling programmes were defined to provide a reasonable estimate of the conditions in the water supply and variations over time and distance. Sanitary inspections (including, for piped water estimates of continuity and leakage) were undertaken whenever samples were collected.
3.5.3.1 Piped water supplies

Sampling of piped water supplies was based on estimated populations served using the inventory, connection review and water usage data. The number of samples to be taken were calculated using the minimum sampling frequencies identified in the 2nd edition of the WHO Guidelines for Drinking-Water Quality (WHO, 1993). For low-income Parishes the number identified was multiplied by a factor of 2 to provide greater coverage of the system, as the numbers using the supply were low and because the project objectives included a focus on low-income areas. However, the monitoring programmes were adjusted as increasing information became available in towns about the quality of the piped water and identified contamination 'hot-spots'.

Sampling points selected varied between sampling rounds and the day that sampling was undertaken varied between months. Samples were usually taken in the afternoon as it was considered that the system would be at greatest risk of contamination, as there was potential for loss of chlorine due to high ambient temperatures (Bailey and Thompson, 1996; Howard, 2001). Sampling in the afternoon also allowed overnight incubation of the samples. In some towns it was possible for field staff to gain access to the service reservoirs and treatment works and in these cases samples were obtained directly from these sites. In other towns access was more problematic and in these cases samples were taken from the taps nearest near the outlet of the works or the service reservoir.

3.5.3.2 Point water supplies

In all towns, the initial water quality related activity was to undertake an assessment of all the point sources within each town. In order to gain a more complete picture of variability in water quality, longitudinal studies were undertaken of selected point sources in Kampala, Mbale, Soroti and Tororo. The selection of sources included in the study was based on the spread of water quality and sanitary inspection data collected during initial assessments of water quality, population density and likely overall use of the springs as determined from the inventory.

The number of sources included was based on practical considerations of the number of samples that could be taken within a month rather on a statistical estimation of
sample size required. In Kampala, 25% of all protected springs available were included, in Mbale all protected springs and about 50% of the boreholes and in Soroti and Tororo roughly 50% of protected springs and boreholes. Following the studies, the monitoring programmes in the four towns included in the study and those in all the remaining towns were based on a rolling programme, where each source was visited at least once per year in the wet season and wherever possible twice per year.

3.5.3.3 Household water sources

The sampling of household water stored in pots and other containers was undertaken in all towns. During the initial period of work in Uganda, water stored within the home was not tested, apart from occasional samples. Initial assessments were undertaken in each town, with samples taken from 10-15 households per Division.

Following the initial assessments, a rolling programme of testing of 10 households per Division was developed linked to ongoing hygiene education. The households selected varied from month to month and were randomly selected by field staff. Sample processing followed the methods described in section 3.5.1.

3.5.4 Sanitary inspections

The sanitary inspection forms used are shown in Annex 4. These were based upon examples of sanitary inspections forms used previously in developing countries which are included in the WHO Guidelines for Drinking Water Quality Volume 3 (1997). The forms were developed by making a series of visits to a sample of water sources within the towns and evaluating likely environmental hazards and the design, construction and operation and maintenance of the sources. The available forms were evaluated to see whether they adequately described the principal risks noted in the Ugandan setting. Where modifications were required these were made. Draft versions of the sanitary inspection forms were then field tested by surveillance staff to see whether they were comprehensible and modifications made as required. Following recommendations of Lloyd and Bartram (1991) and WHO (1997), sanitary inspection forms for each technology were standardised to ensure comparability.
3.5.4.1 Point water supplies

Sanitary inspection forms were developed for the following small point water supplies:

- protected springs
- boreholes/tubewells with a handpump
- dug wells with a handpump

Sanitary inspection forms for each technology included a range of factors that correspond to either hazards, pathways or contributory factors. The different types of factors are shown for each technology in Table 3.3.

<table>
<thead>
<tr>
<th>Risk factor category</th>
<th>Technology</th>
<th>Hazards (question No. from form)</th>
<th>Pathways (question No. from form)</th>
<th>Indirect factors (question No. from form)</th>
<th>Total sanitary risks included on form</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Protected spring</td>
<td>Qu. 8</td>
<td>Qu. 1</td>
<td>Qu. 5</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Qu. 7</td>
<td>Qu. 2</td>
<td>Qu. 6</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Qu.10</td>
<td>Qu. 3</td>
<td>Qu. 9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Borehole with handpump</td>
<td>Qu. 1</td>
<td>Qu. 7</td>
<td>Qu. 5</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Qu. 2</td>
<td>Qu. 9</td>
<td>Qu. 6</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Qu. 3</td>
<td>Qu. 10</td>
<td>Qu. 8</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Qu. 4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dug well with handpump</td>
<td>Qu 1</td>
<td>Qu. 7</td>
<td>Qu. 5</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Qu. 2</td>
<td>Qu. 9</td>
<td>Qu. 6</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Qu. 3</td>
<td>Qu. 10</td>
<td>Qu. 8</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Qu. 4</td>
<td>Qu. 11</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3.3: Risk factors in sanitary inspection forms by question category

3.5.4.2 Piped water

Two forms of piped water supplies were found in the towns in Uganda. The first were provided by utilities, either NW&SC or Municipal Councils, which employed treatment and chlorination. The second were community managed supplies that had
no treatment or chlorination. Sanitary inspection forms were developed to cover each type.

For the piped water supplies managed by utilities, the first approach adopted was to use sanitary inspection forms covering individual taps, which focused on the problems of the immediate sampling area. Some questions regarding problems related to the broader water supply were included, for instance as to whether discontinuity had been experienced within the previous seven days.

From mid-1998, a new inspection form was used that covered a single Parish and included 6 questions regarding the immediate area of the sampling point and 4 questions dealing with broader supply faults. The latter were based on community interview and identification of major faults gained during travel by the field staff through the Parish.

Sanitary inspections of community managed piped supplies also included mains supply faults in addition to risks at the local level. Inspections of these supplies also included assessment of the storage facilities where these existed.

3.5.4.3 Household water

There were limited previous examples of inspection forms for household water storage facilities upon which to draw when developing forms in Uganda. When assessing the range of factors that could potentially affect water quality during household storage, it became apparent that it was more difficult to define a range of yes/no answers. The form developed was therefore somewhat different from those for water supplies and was only used in a small pilot study in Soroti and was not routinely employed.

3.5.5 Water quality and sanitary inspection software development

A water quality and sanitary inspection database - ‘Sanman’ - was developed for this study based on an upgraded and expanded version of software originally developed for a project in Zimbabwe. The software was a relational database developed in Xbase and linked to R&R Report Writer software. The structure of the database is shown in
Figure 3.4 below, which illustrates the relationships between the different databases. A fundamental characteristic of the database design was a procedure to prevent any water quality data and sanitary inspection data from becoming 'orphaned'. Sanitary inspection data could only be put into the database when related to a specific water supply of a defined category and water quality data could only be put into the database when linked to a specific sanitary inspection. Additional fields provided further information about the source, such as management arrangements, zone, town and population served, all of which allowed subsequent stratification for analysis purposes.

![Diagram of the Sanman database structure](image)

**Figure 3.4: Structure of the Sanman database**

The software development was undertaken by DataProcessing with guidance from the author regarding what parameters should be included and what other data would be needed to facilitate analysis and reporting. The initial version of the software was tested in Uganda and subsequent improvements made, particularly with regard to expanding and improving the quality of the reports. All the water quality and sanitary...
data from Uganda were stored on this software. The Ministry of Health retained an overall national database and each town was provided with copies of the software and maintained their own database.

3.6 Access and use of water supplies

Data were collected on the types of water source available and the estimated proportion of the population that used each water source type. The methods used in Uganda to collect the data required on access and use of water supplies were as follows:

1. inventory of all water sources available to those populations without a direct connection to their house or plot;
2. review of data of connections to piped water from water suppliers covering households with water supplied at least one tap at the house plot;
3. studies of water usage behaviour amongst the low-income population where choice of sources was available.

The first two sets of data relate solely to the availability of infrastructure as a means of determining which water sources were available for use by the population and therefore where data on other indicators were of interest. The third set of data related to the actual uptake of services within the urban area as a means of refining the data collection exercises. These methods are described in more detailed below.

3.6.1 Inventory data

This literature indicates that undertaking an inventory of water sources should be the first stage in the development of surveillance programmes (Lloyd and Helmer, 1991; WHO, 1997). Therefore this was the first activity undertaken within each town on inclusion within the study. Lloyd and Helmer (1991) outline the data to be collected during inventory, which they state should include population, identification of water sources which are used, identification of sources for which no data are available, summarising available water quality data, and consolidating epidemiological data. Lloyd and Bartram (1991) also note the need for an initial diagnostic sanitary survey to collect data on aspects such as discontinuity, cost, estimates of quantities of water
used and coverage.

Initial data in Uganda were collected through a review of available records on water sources and water quality and evaluation of available health data. It was noted that available data on water sources such as boreholes, protected springs and public taps and purchase of water from neighbours with a household connection were common.

To obtain the data required, a field survey was undertaken of all sources available for use by households without a connection, including households selling water to their neighbours. The inventory data was collected through the use of questionnaire. A review of the literature yielded little in the way of detailed guidance regarding the nature of such a questionnaire. The questionnaire was therefore developed in Uganda and was designed to maximise the useful information that could be collected to provide a reasonable overview of each source on which to base subsequent data collection. An example of the form used is shown in Annex 5.

The first stage in developing the questionnaire was to identify the likely range of sources that would be found in the urban areas. This was done to ease data collection, allowing the enumerator to simply tick the source type in the appropriate box provided on the questionnaire.

The source categories used are shown in table 3.4 below. It should be noted that in a number of cases, the categories were sub-divided to account for differences in management that could influence one or more of the indicators for which data was collected. Piped water sources were sub-divided into three categories.

Protected springs were divided into two categories on the basis of an assessment of the condition of the headworks. This sub-division was felt to be of importance from the outset in Kampala as initial discussions with sector staff indicated that large numbers of springs were present and therefore some form of priority was needed with respect to initial water quality assessments.

Dug wells were sub-divided into those that had a handpump and those without a

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handpump, as quality in the former was expected to be better than that of the latter group. A further category of unprotected scoop well was introduced to differentiate between deeper wells and those that were very shallow.

<table>
<thead>
<tr>
<th>Nature of source</th>
<th>Source codes</th>
<th>Source description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Piped</td>
<td>PTWS</td>
<td>On-selling by household with private connection</td>
</tr>
<tr>
<td></td>
<td>PSTP</td>
<td>Public tap</td>
</tr>
<tr>
<td></td>
<td>CTTD</td>
<td>Tap provided to a set of dwellings by a landlord</td>
</tr>
<tr>
<td>Protected point source from shallow groundwater</td>
<td>PSGC</td>
<td>Protected spring in good condition</td>
</tr>
<tr>
<td></td>
<td>PSRR</td>
<td>Protected spring requiring repair</td>
</tr>
<tr>
<td></td>
<td>BHHP</td>
<td>Borehole with a handpump or windlass</td>
</tr>
<tr>
<td></td>
<td>DWHP</td>
<td>Dug well with a handpump</td>
</tr>
<tr>
<td></td>
<td>DNWH</td>
<td>Dug well with no handpump</td>
</tr>
<tr>
<td>Rainwater</td>
<td>RRWC</td>
<td>Rainwater collection for communal use</td>
</tr>
<tr>
<td>Unprotected shallow groundwater source</td>
<td>UNPS</td>
<td>Unprotected spring</td>
</tr>
<tr>
<td></td>
<td>UNSW</td>
<td>Unprotected scoop well</td>
</tr>
<tr>
<td>Surface water</td>
<td>PSSL</td>
<td>Lake, stream, river or swamp</td>
</tr>
</tbody>
</table>

Table 3.4 Source types categories used in the inventory form

The inventory data also included the name and location of each source, identifying the level of local Government area (LC1, LC2 and LC3) in which it was found. Data were collected on the age of the source, who constructed it, any major rehabilitation work undertaken, responsibility for operation and maintenance and the frequency with which basic maintenance tasks were performed. The inventory forms also included questions regarding the cost of water and discontinuity.

The questionnaire was field-tested and refined at an early stage in the project. Staff administering the questionnaire in each town were trained in its application. The questionnaire was four pages long and included a set of 22 pre-defined questions. Some of these included simple tick boxes with pre-set categories and some allowed free responses where it was felt that no pre-set categories could be defined. Guidance notes were incorporated into the questionnaire to aid its use. The same form was used
in all towns to ensure consistency within the programme and between the different
towns.

Data were stored electronically to form the basis of a national database. When
considering available software, it was considered desirable that this should be
designed for easy storage of questionnaire data and in particular that the format used
for data storage should be the same as the format of the forms to ease data entry. It
was also desirable that the software should be easily and widely available to aid
subsequent development of local databases.

The data were stored in Epi Info 6.01 developed by WHO and the Centres for
Diseases Control, USA (Dean et al., 1994). This programme was selected because the
data records could be stored in exactly the same format as the questionnaires. This
was felt to be useful in reducing the potential for data entry errors and to make the
data entry process quicker. Epi Info also contains statistics such as chi-square,
correlations and regression analysis that allowed the data to be analysed. The
programme also allows data to be exported to other software should more complex
analyses be required. A final important point was that this programme was shareware,
which ensured that the Ugandan partners would retain access to this software in the
future. As the surveillance programme was trying to achieve sustainability in methods
developed, this was felt to be crucial because there was limited capacity to acquire
more sophisticated and expensive programmes.

Summaries were made of the inventory data at different administrative levels. For
nine of the towns (excluding Kampala) this was done for the LC2, LC3 and LC4
level. In Kampala data were summarised at the LC5 level, but not the LC4 level, as
this level of local Government was largely symbolic in the city and did not have
administrative responsibility. These data were then used in planning subsequent data
collection exercises.

3.6.2 Connection reviews

Connection data were collected and analysed in Kampala using records held by
NW&SC. Records were used to link each connection with geographical areas based
on the address. In the case of the NWSC supplies, the data available were in the form of block maps of 0.5 km² that cover the entire system, but which are not linked to the administrative boundaries. Therefore estimates of population served were derived from a relatively complex process based on a set of assumptions.

A map of connection data from block maps that showed key locating landmarks was obtained. A map of Kampala showing the Parishes and containing the same locating landmarks was then prepared as an overlay onto the connection map.

Connection rates were calculated by assessing which block maps were incorporated into each Parish. Where 90% or more of a block fell within the Parish boundary the total number of connections by category was assigned to that Parish. Where a block did not fall entirely into a Parish, an estimate based on 25 percentiles was made with the corresponding number of connections calculated. The 25 percentile were chosen for convenience and to prevent the development of an overly complicated process.

NWSC had four categories of connection and the numbers of each category in each block were available. These categories are shown in table 3.5 below.

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Category 1</td>
<td>Domestic. Household connections (no differentiation between supplies piped into houses and yard level)</td>
</tr>
<tr>
<td>Category 2</td>
<td>Commercial/industrial</td>
</tr>
<tr>
<td>Category 3</td>
<td>Government/institutional (both houses and flats)</td>
</tr>
<tr>
<td>Category 4</td>
<td>Public taps</td>
</tr>
</tbody>
</table>

Table 3.5: Categories of connection for NWSC supplies

A review of NWSC policy showed that the categories equivalent to a household connection were categories 1 (domestic) and category 3 (government/ institutional) supplies. The numbers of category 1 connections listed in each block map were allocated to a Parish on the basis of the proportion of the block contained within the Parish as described above. The total number of connections was then multiplied by the average household size recorded for each Parish in the 1991 census. This figure
was not corrected for population growth, as it was expected that this would be reflected primarily through numbers of connections rather than increased numbers of people per connection. This gave the population served.

The people who were recorded as living in ‘servants quarters’ in the census were then added to this figure, as they would receive similar a level of service. This was calculated by estimating the number of people living in servants quarters in the 1991 census using equation 3.1. This was done because this population would not have been incorporated within average household size, as such dwellings did not typically contain single families, but groups of individuals or sometimes several families, and population increase would be reflected in relation to people per connection rather than increasing numbers of connections.

In order to estimate the population served by category 3 connections (government/institutional) an assumption was made that all people living in flats will receive water under this category and population increase would be expected to be reflected in relation to people per connection rather than increasing numbers of connections. The population in flats was determined by taking the percentage recorded as living in flats in each Parish in the 1991 census and using equation 3.1 to estimate the population at the time of the review. It was not possible to define a reliable way in which to estimate the population residing in Government owned houses, as government-housing policy was in state of change and therefore this population was not calculated. However, as this was a small proportion of the total (1.7% in the 1991 census), it was not felt that this would distort the final results to a significant degree and the potential inaccuracy was accepted as reasonable.

To obtain an overall figure of coverage for each Parish, the populations served by category 1 supplies (households plus those living in servants quarters) and those served by category 3 supplies were summed. This was expressed as a percentage by dividing this population by the estimated total Parish population.

### 3.6.3 Water usage studies

The inventory data showed that a variety of sources were available in each town. The
literature suggests that different water sources may be used for different purposes (Almedom and Odhiambo, 1994; Madanat and Humplinck 1993). Data were therefore collected through water usage studies of which water sources were used by the population and, for each source, the purpose for which the water was collected.

The target population of interest in the water usage studies was identified as those households living in areas classified as low-income (from the socio-economic index) where the inventory had identified that several water sources were available for use. The aim of the studies was to gain further information about source use, in order to refine the monitoring programmes and to inform improvement strategies. To achieve this aim, specific objectives were defined as follows:

1. to establish whether there were predominant source types used by low-income households;
2. to establish whether there was a differentiation in use of water by source type;
3. to establish the relative importance of different source types for low-income households;
4. to collect data on user experience and perception of water supply adequacy in relation to the key indicators of accessibility, reliability, quality and cost;
5. to be able to calculate likely quantities of water used by low-income households; and,
6. to identify the reasons given by households for using particular water sources.

Water usage studies were undertaken in a sample of towns that were representative of the range of towns included in the surveillance programme. The criteria used for selecting the towns were that the data from the inventory showed multiple source types within low-income Parishes and that the towns selected were representative of a group of towns within the study.

Jinja was excluded from consideration because the inventory showed that 97% of all sources identified were taps and Mukono was excluded because there was no formal piped water system in the town and therefore was unrepresentative of the other towns. The towns selected were Kampala, Soroti and Masaka.
McGranahan *et al.* (1997) outline a number of possible approaches to gathering information concerning water use behaviour patterns in developing countries. In this study, the principal purpose was to develop an urban-wide overview of water use patterns amongst low-income urban communities in order to develop appropriate monitoring strategies, rather than looking at local variations in use patterns. McGranahan *et al.* (1997) and UNICEF (1995) suggest that broad-spectrum surveys using a household questionnaire was appropriate to obtain the information required.

A questionnaire was developed for the purposes of the study and is shown in Annex 6. In addition to questions designed to gain information to meet the objectives noted above, data were also collected on which family members collected water, socio-economic variables, diarrhoea incidence and whether water was treated within the home.

The questionnaire was developed in two stages. A provisional questionnaire was devised and tested for face validity in 10 LC1 communities in Kampala. The questionnaire allowed free responses to a set of questions regarding source type, use and proximity, as well questions on the use of vendors and rainwater and reasons for source use.

In selecting the communities, two criteria were used. The first was that the community had to be in Parishes defined as low-income based on the socio-economic index described in section 3.12. The second criterion was that there should be more than one source type in the community identified from the inventory. Each community that met the criteria was allocated a number and the communities selected using a random numbers table from Barnett (1991).

In common with other social surveys in developing countries, the questionnaire data was triangulated with focus group discussion and observation (McGranahan *et al.*, 1997). Although it was proposed to undertake the water usage studies on a Parish (LC2) level, the pilot stage used LC1 communities to allow more intensive data collection to help develop the final methodology. For focus group discussions, 'topic
guides’ were prepared based on similar types of activity reported in the literature to provide prompts to the facilitator of the group (Almedom et al., 1997).

Volunteers from the Uganda Red Cross Society undertook the fieldwork during this testing stage. The volunteers were split into two groups, one group who would act as enumerators and administer the questionnaire and a second group to undertake focus group discussions. The volunteers received training in the administration of the questionnaire and in conducting focus group discussions prior to the start of the exercise.

Enumerators administering the questionnaires were allocated specific communities and asked to complete 25 questionnaires each day. Households were selected using a systematic random approach (Barnett, 1991). The interviewer moved along a transect through the community from an initial central starting point. It was decided that questionnaires were to be completed at every 5th house on the right. In order to meet with Ministry of Health ethical guidelines for research, households were free to refuse to participate in the study. Where a household refused to participate, interviewers went to the next house that agreed to do an interview and then selected the 5th house on the right from the last participating household.

Enumerators were instructed to ask the questions exactly how they appeared on the questionnaire and if the respondent did not understand the question to leave this blank.

The focus group discussion was facilitated by one Red Cross volunteer with a second volunteer acting as rapporteur, following usual practice in focus group discussion when tape recording was not used (Almedom et al., 1997). At the start of the focus group discussions, the facilitators ensured that the purpose of the discussion was clear to the participants and agreed a set of ground rules:

- Confidentiality – no one was to be identified in a report
- Only one person should speak at a time
- Every member of the group was encouraged to speak
There are no right or wrong answers just different opinions.

The groups initially prepared a map of their community using a set of agreed symbols to mark water sources and major landmarks within the community. The participants were asked to discuss the importance of different water sources and indicate which sources were used by most people and the reasons for using different sources. The map and notes from the discussions were agreed by all participants, signed by the facilitator and then handed to the study team for analysis.

Observations of where community members went to collect water were also carried out. This was done by local community officials who were asked to record how many men, women and children visited each source in their area. Observations were performed in the early morning, midday and the late afternoon and covered a one-hour period on each observation visit. These times were selected as they were those when water collection was most likely to occur.

Once the study was completed the data were used to refine the questionnaire in order to undertake the studies. The data from free responses were analysed and categories of answers were defined for source use and reasons by creating codes to cover a cluster of responses with the same meaning, a commonly used technique in social surveys (Nichols, 1991). To do this, a group of three people – the author, a colleague in the Ministry of Health and an expert in social surveys was formed. Each person in the group took a copy of the full set of questionnaires and developed a set of categories for use of water and reasons for source selection based on responses that they considered to represent a common theme. For instance, a category of ‘quality’ could include responses from the initial questionnaire such as: ‘the water is good’; ‘the water is clean’; and, ‘the water is safe’.

The group then met to present the categories they had developed and these were reviewed in terms of coherence and through discussion a consensus was obtained on a final set of categories. A sample of the questionnaires was then selected and each member of the team asked to categorise the free responses using the set of categories agreed. The team then met again as a group and evaluated the results of this exercise.
as a measure of category reliability. Where there were discrepancies, additional
categories were defined and the reliability exercise repeated until consensus was
obtained.

The information from the focus group discussions and observation was used to
evaluate the reliability of the data obtained from the questionnaire and assess whether
there had been enumerator bias in administering the questionnaires. This was done by
checking whether there were discrepancies between the questionnaire data and the
data from the focus group discussions and observations in the proportion of
households identified using particular source types. The reasons for source use
provided from the questionnaire were also evaluated against the data from the focus
group discussions to assess whether major discrepancies existed.

Once the data had been analysed and there was consensus regarding the categories to
be used in the questionnaire, a final questionnaire was devised. This was translated
and back-translated into local languages by two different sets of Ugandan staff from
Makerere University and the Ministry of Health to ensure that where the questions
were asked in the local language, the meaning and content was consistent.

3.6.3.1 Full studies

For the studies undertaken in Kampala, Soroti and Masaka, environmental health staff
involved in the surveillance programme were used as enumerators. Enumerators were
trained in the administration of the questionnaire, including how to categorise free
responses given to questions regarding source use and reasons for source selection. In
Kampala and Soroti, the questionnaires included a number of categories covering
major domestic uses and reasons for the selection of the source. In Masaka, an
abbreviated version of the questionnaire was used that limited the categories for use to
consumptive (drinking and cooking) and non-consumptive domestic use and omitted
sections on reasons. This was done to assess whether more limited data would still
support decision-making.

The target populations in each study were households living in areas defined as low-
income using the socio-economic index and where data from the inventory showed
that there was more than one type of water source within a Parish. The Parish level was selected as the evidence from the pilot study suggested that collection of water from sources outside the Parish was not common.

Women were the preferred interviewees as they are generally considered to be the principal household water managers, however, both men and children over the age of 14 were also accepted by the study team (Howard et al., 2002a). Ethical considerations required that participation in the studies should be based on informed consent. At each household, the enumerator provided a brief introduction regarding the purpose of the study, how the data would be used and that confidentiality was guaranteed. Verbal consent was obtained from all respondents prior to the administration of the questionnaire and households were free to decline to participate. Enumerators were instructed to abandon the study if very large numbers of households declined to participate in order to avoid bias. The studies were approved by the Municipal Councils of each town and by the Ministry of Health.

3.6.3.2 Sampling strategy

The sampling strategy developed was based on a multiple-level stratified approach (Barnett, 1991; UNICEF, 1995). The unit of study was identified as being the household and the criteria for inclusion in the study were households residing in low-income Parishes where there was more than one type of water source. The primary sampling unit was the Division in each town and the secondary sampling unit was the Parish. The number of households meeting the criteria in each Division were calculated using equation 3.3 below.

\[
\text{Equation 3.3: } Nh = \frac{P_{1999}}{D}
\]

Where:

\(Nh\) = Estimated number of households in 1999

\(P_{1999}\) = Estimated population in 1999

\(D\) = Average household size recorded in 1991

Each Division in Kampala and Soroti was allocated an appropriate number of
questionnaires based on the proportion of the total target population living in the Division. A pre-set number of questionnaires (45 in Kampala and 20 in Soroti) were determined for simplicity in sample design. A random sample of Parishes in each Division that met the criteria was selected by allocating a number to each Parish meeting the criteria and then selecting Parishes using a random numbers table from Barnett (1991). In Masaka, whilst there are three Divisions, there were only two Parishes in each. Data were collected from only one Division as the two Parishes had the lowest socio-economic status in the town and both had a choice of water source types. Within-Parish sampling used the systematic approach used in the pilot stage.

3.7 Other indicators of water supply

3.7.1 Discontinuity

Data for discontinuity were collected in three principal ways in order to reflect the different causes, predictability and frequency of occurrence. In addition, water suppliers were interviewed at the outset of the programme to ascertain whether a systematic rationing of water supply was in place in their water supplies.

Data were collected during inventories through community interview regarding whether users of a source ever experienced an interruption in the supply. Discontinuity was defined as being the physical absence of water flowing from the source that usually provided water and not disconnection due to non-payment. Data were collected in response to two questions. The first was a question regarding whether the source ever dried up. If the answer to this question was 'Yes' then the respondent was asked to provide further basic information about frequency of discontinuity; whether daily, monthly, seasonally or occasionally. Seasonally and occasionally were differentiated by their predictability, with seasonal shortage reflecting an event that occurred every (or most) year(s) and occasionally being an unpredictable event of relatively low frequency.

Data were also collected during the water usage studies in Kampala and Soroti. Questions were asked regarding whether the first or second choice water sources ever experienced interruption to the supply. When the answer was 'Yes', respondents were
asked how often this occurred. The enumerators categorised responses as either: every day; at least once a week; at least once a month; in the dry season; or, only occasionally.

Data on discontinuity in piped supplies were collected through community interview as part of sanitary inspection. One or more households within the Parish were asked whether they had experienced interruption in supply within the previous one week. Any positive answer was taken as indicating failure. This was justified because, although recall would have decreased with time, in most cases it was expected that interruption in the supply was a sufficiently significant event in the experience of water collection that it would be likely to be remembered. Previous work on surveillance projects in developing countries has indicated that this approach is appropriate and provides reliable data (Lloyd et al., 1991; WHO, 1997).

3.7.2 Cost of water

The principal focus of the surveillance data collection was the purchase price of water at the point of collection. This was done through the inventories completed in all towns and the water usage studies. In the inventories, data were collected regarding whether payment was required at the source from either the caretaker or a user present at the source at the time of the visit. Respondents were asked whether they paid for water at the source and when the answer was ‘No’, then no further questions were asked. Where the answer was ‘Yes’, respondents were asked how much they paid and for what volume of water and the equivalent cost per standard 20 litre Jerrycan (the most common form of container used to collected water) was calculated. This is illustrated in figure 3.5 below. More than one answer for any one individual source was allowed to account for situations where sources required dual payment, for instance purchase on collection and a second more general payment such as a monthly tariff.

Data on purchase prices were also collected during the water usage studies in Kampala and Soroti but not in Masaka. Respondents were asked whether they paid for water collected from the sources identified as their first and second choice water sources in addition to the cost paid when water was purchased from a vendor. These
questions are of the same format and followed the same flow as the questions included in the inventory questionnaire.

Figure 3.5: Obtaining data on costs of water

Data were also collected from the water supplier regarding the tariffs applied for different levels of service and for different components – capital investment costs and unit tariffs – to act as a comparison to the data collected on the purchase price at the point of collection. This data was available from NWSC via leaflets explaining their costs and billing procedures for the general public. Data on tariffs for the municipal council operated water supplies were not available.

3.7.3 Leakage

Data on leakage were only collected for piped water supplies. Data were collected as part of sanitary inspections carried out during water quality sampling in relation to the
potential impact on water quality failure and as an overall measure of operation and maintenance. The health inspector or assistant performing the sanitary inspection was asked to note whether there were any signs of leakage within a Parish. These included water that could be seen leaking from a pipe or the collection of water along the line of the pipe. The field staff also asked community members whether any pipe bursts had been noted in the previous week in their Parish. This data was therefore only qualitative and would be expected only to detect major leaks.

3.7.4 Quantities of water

The collection of water quantity data was limited to the water usage studies. The enumerators asked what size of container was used to collect water and how many containers were filled each day. Data were also collected regarding the number of people residing in the house. A per capita figure of water consumption was obtained for each household using equation 3.4 below.

\[
V_{pc} = \frac{V_c \times N_c}{N_h}
\]

Where:

- \(V_{pc}\) = Volume per capita collected
- \(V_c\) = volume of containers used
- \(N_c\) = Number of containers collected
- \(N_h\) = Number of people residing in the household.

In most cases the calculation was based on water collected from the first choice water source, but in a few cases the second source was used where the daily volume was greater and the data showed no difference in frequency of use.

3.8 Data analysis

Data analysis was undertaken using a variety of software packages, including SPSS, Epi Info, Lotus 123 and MS-Excel. The data from the inventories and water usage studies were primarily binomial categorical data and therefore non-parametric tests such as odds-ratios, \(\chi^2\) (chi-square) and logistic regression were used. Where the data
analysed were percentages, for instance numbers of households giving particular reasons for source selection, a range of parametric and non-parametric tests were performed including Spearman's rank correlation, Kruskal-Wallis tests and analysis of variance (ANOVA). Each analysis had a defined null hypothesis and only where analysis produced results significant at the 95% \( (p = 0.05) \), 99% \( (p = 0.01) \) confidence levels of higher were null hypotheses rejected.

Much of the water quality data was analysed using non-parametric tests. Helsel and Hirsch (1992) note that the use of non-parametric tests is common in analysis of water resources data and shows no loss of power in comparison to parametric tests. The microbiological water quality data was ordinal and by graphing out the data, it was determined that it followed a log-normal distribution. The data included default numerical values for results of bacteria being too numerous to count and therefore median rather than means are used, as recommended by Helsel and Hirsch (1992). Analysis of these data was in general through non-parametric tests such as Spearman's rank. Analysis of chlorine residual data was limited to frequencies and averages. When comparing microbiological and chlorine residual data, \( \chi^2 \) and Spearman's rank correlation were used as the data were non-normal.

When analysing microbiological data in comparison to sanitary inspection data, tests performed were non-parametric, as the sanitary inspection data was non-normal. In a number of cases water quality data were transformed into binomial categorical data based on particular water targets and therefore non-parametric tests such as \( \chi^2 \) and odds ratios were used. The use of non-parametric statistics is recommended by Tillett et al. (2001) as being most appropriate for microbiological data. The sanitary inspection data are all binomial categorical data and again therefore analysis used non-parametric tests.

Combined analysis of water quality and sanitary inspection data was through contingency tables, using dummy binomial categorical data for water quality, defined in relation to specific water quality targets using the relevant procedures of the software packages used. As there were multiple risk factors, the combined analysis also used logistic regression models. These models include a number of key terms as
described by Hutcheson and Sofroniou (1999). These are the model log estimate (-2LL) which is a goodness of fit measure of the model and determines the degree to which the observed values deviate from the predicted values. For each variable, a regression co-efficient is defined, as well as the standard error associated with the predicted value of the dependent variable. The Wald statistic is also provided for each variable, which tests the hypothesis that the regression co-efficient for the explanatory variable is zero (has no effect on the dependent variable). Hutcheson and Sofroniou (1999) note that the Wald tends to exaggerate the significance of variables with high co-efficient values and therefore suggest using the model log estimate for the overall model.

The analysis of water quality data with sanitary inspection data required manipulation of the data and the definition of dummy coded binary variables in SPSS. These are variables that transform continuous data (such microbiological data) into discrete categorical data on the basis of exceeding or meeting a specified water quality target. For piped water, dummy coded binary variables were used for microbial quality, the presence or absence of thermotolerant coliforms (absence = 0, presence = 1) and for both free and total chlorine meeting a minimum concentration of 0.2mg/l (No = 0, Yes = 1).

For boreholes the dummy coded variable for presence or absence of thermotolerant coliforms was used in data analysis with sanitary inspection data. For community-managed piped water supplies, two dummy coded variables were used, presence or absence of thermotolerant coliforms and contamination exceeding 10 cfu/100ml, which is suggested by WHO (1993) as being acceptable for untreated community-managed water supplies. The data were coded as follows: <10cfu/100ml = 0, ≥10cfu/100ml = 1. For protected springs the two dummy coded variables used for community managed piped water supplies were used and in addition contamination exceeding the Uganda guidelines for untreated supplies of 50cfu/100ml (<50cfu/100ml = 0, ≥50cfu/100ml = 1).

Analysis of discontinuity, leakage and quantity data was restricted to frequencies and averages. When comparing data with source type the χ² test were used.
Chapter Four

Programme development, socio-economic status and urban zoning results from field studies Uganda

4.1 Introduction
This chapter presents the first component of the results of the field studies undertaken in Uganda, covering the programme development, socio-economic status and the data from the urban zoning methodology. The chapter is split into three sections:

4.2 summarises the development of the surveillance programme in Uganda, including institutional arrangements and implementation cycle within each town;
4.3 summarises the data on socio-economic status of the towns in the studies and provides the results of statistical analyses; and,
4.4 summarises the data used in the zoning of urban areas and provides the results of statistical analyses.
4.2 Programme development

4.2.1 Institutional framework

The institutional review identified the Government institutions with responsibility for water quality, water supply and public health and also identified a range of organisations with an interest in water supply in urban areas.

As a result of this review, the Environmental Health Division of the Ministry of Health was identified as the appropriate national body to co-ordinate the surveillance activities as they had a national mandate for environmental health protection. The Division was staffed by Health Inspectors, whose training ranged from diploma to MSc level. The role of the Ministry of Health within the surveillance programme was to support the training and supervision of staff in Municipal Councils and to consolidate data at a national level, which is consistent with the expected role of national Government institutions in Uganda.

The Public Health Departments in each urban local authority undertook implementation of surveillance activities within urban areas. A Medical Officer typically headed these units for Health supported by a team of Health Inspectors and Health Assistants. Health Inspectors follow a three-year diploma source and Health Assistants a three-year certificate course in environmental health. These staff were well placed to carry out surveillance activities because their training includes the impacts of poor water, sanitation and hygiene on health. They also had skills in low-cost water supply provision and the delivery of health education and worked in the communities they serve.

There are five levels of local government in Uganda, differentiated by the suffix LC, which refers to Local Council. These, in order of decreasing size, are: LC5 (District), LC4 (County), LC3 (sub-County), LC2 (Parish) and LC1 (zone, cell or village). Of the towns included only Kampala had an LC5 level of Government, in each of the other towns the Municipal and Town councils were LC4. Each town was sub-divided into a set of Divisions at the LC3 level, within which were a number of Parishes with LC2 councils. Each Parish was then sub-divided into a variable number of LC1
committees. The urban councils were asked at which levels the majority of planning and implementation of activities occurred and these were identified as LC3 and LC2. Detailed data were also available down to the LC2 level, but not to the LC1 level. It was therefore decided that the lowest unit of interest within the study would be the LC2 level.

There was a strong commitment to engage the water supply sector and other stakeholders at all stages of the project, which was achieved through regular meetings and inclusion of water supply staff in training events. The roles of each stakeholder are summarised in table 4.1 below.
<table>
<thead>
<tr>
<th>Organisation</th>
<th>Expertise</th>
<th>Role within Uganda</th>
<th>Role in surveillance programme</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ministry of Health (MOH)</td>
<td>Environmental and public health; water and sanitation</td>
<td>Policy development, technical guidance and supervision of local Government implementation</td>
<td>Training; support supervision; consolidation of data; strategy and policy development; advocacy for water supply improvement; national reporting</td>
</tr>
<tr>
<td>Local Government Public Health Departments</td>
<td>Environmental and public health; water and sanitation</td>
<td>Service provision; implementation of local and national programmes</td>
<td>Implementation of surveillance, reporting to communities; reporting to water sector; reporting to MoH; implementation of hygiene education and water source improvement</td>
</tr>
<tr>
<td>National Water and Sewerage Corporation</td>
<td>Piped water supply operation, maintenance and management; water quality control</td>
<td>Provision of water supplies and quality control in 11 towns</td>
<td>Water quality control; participation in training; improvement in piped water supply</td>
</tr>
<tr>
<td>Directorate of Water Development (DWD)</td>
<td>Water supply planning and provision</td>
<td>Policy development, technical guidance and supervision to local Government; periodic water quality analysis of Municipal water supplies; sector regulation</td>
<td>Participation in round-table discussions; support to Municipal councils to improve water supplies; periodic water quality analysis of Municipal water supplies</td>
</tr>
<tr>
<td>Donors agencies (UNICEF, WHO, DFID, DANIDA)</td>
<td>Guidance on water supply provision and public health</td>
<td>Support to national and local Government; support to NGOs</td>
<td>Participation in round-table discussions; support to national and local Government in policy, strategy and implementation</td>
</tr>
<tr>
<td>NGOs (SCF, Plan International, WaterAid)</td>
<td>Water supply and sanitation</td>
<td>Implementation of water supply and other projects with communities</td>
<td>Participation in round-table discussions; use of data in water supply improvements</td>
</tr>
</tbody>
</table>

Table 4.1: Roles of different organisations identified in Uganda
4.2.2 Towns selected

The towns selected are shown in table 4.2 below, with details of their 1991 populations and estimated populations for the year 2000 (the last year of fieldwork). The locations of these towns within Uganda are shown in figure 2.3 in the previous chapter.

<table>
<thead>
<tr>
<th>Town</th>
<th>Year included in project</th>
<th>Location in Uganda</th>
<th>Population 1991 census</th>
<th>Est. 2000 using WRI (1996) growth rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entebbe</td>
<td>1999</td>
<td>Central</td>
<td>42,763</td>
<td>64,987</td>
</tr>
<tr>
<td>Jinja</td>
<td>1999</td>
<td>Central</td>
<td>65,169</td>
<td>99,038</td>
</tr>
<tr>
<td>Kabale</td>
<td>1998</td>
<td>Southwest</td>
<td>29,246</td>
<td>44,445</td>
</tr>
<tr>
<td>Kampala</td>
<td>1997</td>
<td>Central</td>
<td>774,241</td>
<td>1,176,618</td>
</tr>
<tr>
<td>Masaka</td>
<td>1998</td>
<td>Southwest</td>
<td>49,585</td>
<td>75,355</td>
</tr>
<tr>
<td>Mbale</td>
<td>1998</td>
<td>East</td>
<td>53,987</td>
<td>82,044</td>
</tr>
<tr>
<td>Mbarara</td>
<td>1998</td>
<td>Southwest</td>
<td>41,031</td>
<td>62,355</td>
</tr>
<tr>
<td>Mukono</td>
<td>1999</td>
<td>Central</td>
<td>7,400</td>
<td>10,686</td>
</tr>
<tr>
<td>Soroti</td>
<td>1998</td>
<td>East</td>
<td>40,970</td>
<td>62,262</td>
</tr>
<tr>
<td>Tororo</td>
<td>1998</td>
<td>East</td>
<td>26,783</td>
<td>40,702</td>
</tr>
</tbody>
</table>

Table 4.2: Towns included in the field study

The estimated populations are based on the growth rate of 4.76% recorded by the World Resources Institute (1996) rather than the inter-census growth rate recorded in the 1991 census. This figure was taken as the growth rates calculated for Uganda did not differentiate between rural and urban populations at the national or District levels. Therefore with the exception of Kampala (which is a single District), specific urban growth rates were not obtainable and the District growth rates were likely to underestimate urban growth. For instance, Soroti District as a whole showed a very low long-term growth rate, which is likely to be influenced by out-migration from the District by insecurity at the end of the 1980s. However, the town itself almost certainly grew significantly during this time, as most migration was from rural areas, often to the town of Soroti (Soroti Municipal Council, personal communication).
The decision to use the growth rate recorded by the World Resources Institute is supported by the 1999 Human Development report for Uganda that indicated an urban growth rate of 4.7% (UNDP, 1999). This approach will have certainly failed to capture the variability of growth between and within towns, which is unlikely to have been equal, but in the absence of more reliable data was felt to be a reasonable assumption.

4.2.3 Implementation of activities

Fieldwork for the project was initiated in September 1997 and lasted until March 2000. The cycle of activities in each town is discussed in the next section. This section provides a brief overview of overall project development. An initial period was spent with staff from the Ministry of Health and field staff from Kampala City Council to develop and review data collection methods. Work was then initiated in Kampala in October 1997 as the first stage in the project. The project then moved to the three towns in the east of Uganda in early 1998. Activities were initiated in the three towns in Southwest Uganda in late 1998, with the final set of three towns in Central Uganda included in mid-1999.

The programme of activities for each town passed through a number of critical stages as shown in Figure 4.1 below.
Figure 4.1 Programme development within each urban area

4.2.4 Training of staff

Staff undertaking surveillance work were trained at workshops lasting one week, following a timetable shown in Annex 7. Each course included both the local authority environmental health staff and local representatives of water supply agencies. With the exception of Kampala, each course brought together staff from a
number of towns to maximise information sharing. After the formal training, follow-up field training was carried out in each town to provide field staff with further opportunities to seek clarification on key issues.

Ongoing training of surveillance staff was carried out to provide an opportunity for upgrading their skills, to share experiences and develop and refine surveillance and intervention strategies. This was carried out through participatory refresher training courses in which the participants defined the areas of importance and the agenda to be followed. A key element of these training courses was that it facilitated a process of local networking that allowed lessons learnt in one area or town to be shared and discussed with staff from other towns and areas. In addition, a specific event was held to develop participatory health education materials and tools.

4.2.5 Reporting mechanism

The development of reporting mechanisms for communities, local authorities and national bodies was undertaken as part of the assessment and these were incorporated into the routine monitoring programmes. These reporting mechanisms included direct feedback of results to communities using the forms shown in Annex 8 and holding of community meetings to discuss results and the implications of the surveillance findings. In addition, reports were established for local authorities and a system of national reporting was also developed, see Annex 9. This reporting was linked to recommendations for action to improve source water quality and household water handling. A summary of the information included in reports to each target audience is summarised in table 4.3 below.
<table>
<thead>
<tr>
<th>Target audience</th>
<th>Method of reporting</th>
<th>Frequency</th>
<th>Summary of information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communities</td>
<td>Reports from field staff</td>
<td>Monthly</td>
<td>Objectives of surveillance; identification of where samples taken; note of where contamination found; qualitative estimate of degree of contamination (e.g. very high, high, low); identified sanitary risks; recommendations for action.</td>
</tr>
<tr>
<td>Meetings</td>
<td>Rolling programme</td>
<td></td>
<td>Objectives of surveillance; implications of findings; discussions of actions to improve water supplies</td>
</tr>
<tr>
<td>Local Government</td>
<td>Reports from field staff</td>
<td>Monthly</td>
<td>Samples and inspections taken; summary of findings; summary of actions taken; recommendations for future activities</td>
</tr>
<tr>
<td>Water suppliers</td>
<td>Reports from field staff</td>
<td>Monthly</td>
<td>Samples and inspections taken; summary of findings; summary of actions taken; recommendations for action by supplier</td>
</tr>
<tr>
<td></td>
<td>Reports from MoH and meetings</td>
<td>Quarterly</td>
<td>Findings of surveillance activities; summary of supplier performance; summary of actions taken; recommendations for action by supplier</td>
</tr>
<tr>
<td>NGOs</td>
<td>Reports from MoH and field staff</td>
<td>On demand</td>
<td>Findings of surveillance activities; recommendations for action by stakeholders for interventions</td>
</tr>
<tr>
<td>Other stakeholders</td>
<td>Meetings</td>
<td>Quarterly to six-monthly</td>
<td>Findings of surveillance activities; summary of actions taken; implications of findings, discussion and recommendations for action</td>
</tr>
</tbody>
</table>

Table 4.3: Summary of reports on surveillance activities and findings provided to different target audiences in Uganda

### 4.3 Socio-economic data

The socio-economic variables selected are shown in Table 4.4 below. Variable weighting reflects the sensitivity of the variable to socio-economic status, with higher weights indicating greater sensitivity. Within each variable, there are a number of conditions. The scores allocated reflect the level of socio-economic status indicated, with −5 being very low and +5 being very high and 0 representing an average condition. The upper and lower boundaries of condition scores were based on those identified by researchers who have used socio-economic indices in developing countries previously (Caroline Hunt 1998, personal communication).
<table>
<thead>
<tr>
<th>Variable</th>
<th>Variable weight</th>
<th>Conditions</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roof material</td>
<td>4.0</td>
<td>Iron sheets</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tiles</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Asbestos sheets</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Concrete</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Papyrus</td>
<td>-3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Grass</td>
<td>-4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Banana leaves/fibre</td>
<td>-5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Other</td>
<td>-5</td>
</tr>
<tr>
<td>Floor material</td>
<td>4.0</td>
<td>Concrete</td>
<td>-1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Brick</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Stone</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cement screed</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rammed earth</td>
<td>-5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Wood</td>
<td>3.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Other</td>
<td>-5</td>
</tr>
<tr>
<td>Persons per room</td>
<td>2.5</td>
<td>&lt;1.7</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.8-2.1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt;2.1</td>
<td>-1.5</td>
</tr>
<tr>
<td>Educational attainment</td>
<td>2.0</td>
<td>None – male</td>
<td>-3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>None – female</td>
<td>-3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>P1-P7 – male</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>P1-P7 – female</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>S1-S4 – male</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>S1-S4 – female</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>S5-S6 – male</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>S5-S6 – female</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>University – male</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>University – female</td>
<td>3</td>
</tr>
<tr>
<td>Main source of livelihood</td>
<td>2.0</td>
<td>Subsistence farming</td>
<td>3.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Commercial farming</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Petty trading</td>
<td>-4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Formal trading</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cottage industry</td>
<td>-1.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Property income</td>
<td>4.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Employment income</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Family support</td>
<td>-5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Other</td>
<td>-4.5</td>
</tr>
<tr>
<td>Average household size</td>
<td>1.0</td>
<td>&lt;3.4</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.4 - 4.3</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.4 - 4.7</td>
<td>-1.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt;4.7</td>
<td>-1.5</td>
</tr>
</tbody>
</table>

Table 4.4 Socio-economic index variables and conditions with weightings

On the basis of the socio-economic criteria selected the Parishes in each town were assigned to low, medium and high income, based on the score for each Parish relative
to the average for each town. Details of the Parishes and their socio-economic status are provided in Annex 10. A summary of the results showing the number of Parishes falling into three categories of socio-economic status (low, medium and high) is shown in table 4.5 below.

<table>
<thead>
<tr>
<th>Town</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entebbe</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Jinja</td>
<td>5</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Kabale</td>
<td>5</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Kampala</td>
<td>56</td>
<td>16</td>
<td>17</td>
</tr>
<tr>
<td>Masaka</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Mbale</td>
<td>5</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Mbarara</td>
<td>3</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Mukono</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Soroti</td>
<td>6</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Tororo</td>
<td>4</td>
<td>3</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 4.5: Number of Parishes in socio-economic groups in each town

The socio-economic index showed that there was a wide range in relative wealth in each town, providing a clear indication of priorities for the surveillance programme. This was most pronounced in Kampala where the number of Parishes was greatest. In a few Parishes in Kampala there had been significant changes in status since the 1991 census. Such changes are to be expected and work in the UK has suggested that whilst relative scoring and weighting of variables does not change significantly over time, areas may see either improvement or worsening in levels of socio-economic status over time (Jarman, 1984). In Kampala, it was decided to introduce a new category (low-medium income) to reflect changes in socio-economic status. Table 4.6 below indicates the number of low, low-medium, medium and high income Parishes found in each Division and the average score for the Division.
Table 4.6: Distribution of Parishes by socio-economic class, Kampala

These data show that low-income Parishes are found in each Division suggesting that a targeted surveillance programme would need to operate throughout the City. Low-income Parishes were also found in the city cores (inner city slums) and on the periphery of the city.

4.4 Zoning of urban areas

The zoning of urban areas was designed both as a means of first-stage assessment to target resources and to ensure that water sources were sampled at a frequency commensurate with their importance to the population. As discussed in section 3.7, the zoning methodology incorporated three sets of data:

1. socio-economic status (using the data from the socio-economic index described in section 4.3);
2. population density; and,
3. ‘water economy’ (a measure of connection rate, availability and use of water sources).

Population density was used to develop sub-categories of low-income Parishes, which was of greatest value for Kampala with its greater number of Parishes and wide variation in density. In the other towns, densities were in general much lower and differences less pronounced.
In Kampala, the variation in population density across the City was significant as shown in table 4.7 below. This illustrates that high density low-income Parishes are only found in Central, Makindye, Kawempe and Rubaga Divisions. Nakawa has no high density Parishes. Medium density, low-income Parishes are mainly found in Kawempe and Nakawa Divisions and low-density, low-income Parishes are found in all Divisions except Central Division.

<table>
<thead>
<tr>
<th>Division</th>
<th>No. low-income and low-medium income Parishes</th>
<th>No. low density</th>
<th>No. medium density</th>
<th>No. high density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central</td>
<td>7</td>
<td>0</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td>Kawempe</td>
<td>17</td>
<td>4</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>Makindye</td>
<td>13</td>
<td>4</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>Nakawa</td>
<td>9</td>
<td>4</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Rubaga</td>
<td>10</td>
<td>4</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Total</td>
<td>56</td>
<td>16</td>
<td>14</td>
<td>26</td>
</tr>
</tbody>
</table>

Table 4.7: Distribution of low and low-medium income Parishes by population density in Kampala

The water economy measure was also used to develop sub-categories of low-income Parishes. Where only one form of water supply was found in the Parish from the inventory (which was only true for piped water), the Parish was classified as relying primarily on piped water. Parishes where there were a variety of source types available and the rate of connection was low were categorised as having a ‘mixed’ water economy. There were a few Parishes where the inventory indicated no taps and the connection rates were low and these were initially considered as relying solely on protected point sources. However, the water usage study indicated that in no Parishes were the water sources used sufficiently dominated by point sources to justify this category and thus this sub-category was dropped and all these Parishes included in the mixed water economy sub-category.

4.4.1 Zone categories

Using the sets of data noted above, the zone categories were finalised. The zoning resulted in 33 zone types, which was considered of little practical use. The final
zoning developed incorporated only 10 zone categories, which were based on field data were primarily applied in Kampala. The zone categories, the number of Parishes in Kampala falling into each category and the priority of each category for the surveillance programme are shown in table 4.8 below and in more detail in Annex 11.

<table>
<thead>
<tr>
<th>Zone</th>
<th>Description</th>
<th>Parishes</th>
<th>Priority</th>
</tr>
</thead>
<tbody>
<tr>
<td>LHMX</td>
<td>Low income, high density, mixed water source use</td>
<td>22</td>
<td>1</td>
</tr>
<tr>
<td>LMMX</td>
<td>Low income, medium density, mixed water source use</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>LHPP</td>
<td>Low income, high density, principally piped water use</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>LLMX</td>
<td>Low income, low density, mixed water use</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>LLPP</td>
<td>Low income, low density, principally piped water use</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>L/MMMX</td>
<td>Low-medium income, medium density, mixed water use</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>L/MLMX</td>
<td>Low-medium income, low density, mixed water use</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>L/MMPP</td>
<td>Low-medium income, medium density, principally piped water use</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>MEDM</td>
<td>Medium income, direct connections and use of communal piped water use</td>
<td>16</td>
<td>9</td>
</tr>
<tr>
<td>HIGH</td>
<td>High income, direct connections coverage very high</td>
<td>17</td>
<td>10</td>
</tr>
</tbody>
</table>

Table 4.8: Urban zones categories for Kampala

For the zoning to be effective, the priority that would be accorded to a zone on the basis of the above methodology should be linked to the vulnerability to water-related disease. The data were therefore analysed with data from the 1997/98 cholera epidemic in Kampala using the Spearman’s rank correlation statistic to see whether any relationship existed. The data on cholera incidence did not differentiate between Parishes of the same name but different numerical suffix (e.g. Kamwokya I and II). Therefore all Parishes with the same name but different numerical suffix were excluded from the analysis. The null hypothesis was that no significant relationship would be found between the priority accorded to zones and numbers of cholera cases. The analysis gave a correlation significant above the 99% confidence level (Rs =
-0.49, \ p = 0.001) and the null hypothesis was rejected and a significant relationship between zone priority and cholera cases accepted.

As the socio-economic status and connection rate to the water supply were considered likely to be particular confounding variables, these were tested individually against the cholera cases with the same null hypothesis. The test for socio-economic status gave a result that was not significant (Rs = -0.16, \ p = 0.294) and the null hypothesis was accepted. The test for connection rate gave a result that was significant to the 95\% confidence level (Rs = -0.35, \ p = 0.018) and the null hypothesis was rejected and a significant negative relationship between proportion of households with a household connection and cholera cases accepted. These analyses show, however, that correlation is strongest with the zoning priority indicating that a multivariate approach is more useful than sole use of connection rate.

Zoning was used as an assessment tool for directing the resources of the surveillance programme into those Parishes with populations most vulnerable to water-related health risks. Data acquisition was focused on those Parishes falling into categories ranked 1-7 in table 4.8, where more extensive data collection was required to characterise vulnerability to water-related health risks and water supply arrangements. Far less attention was paid to those Parishes in categories ranked 8-10 as characterisation in relation to water supply arrangements and water-related health risks was relatively simple. The data collected in the Parishes in categories 8-10 primarily focused on piped water supply and was designed to ensure data covered the entire system.

The use of zoning significantly reduced the number of Parishes to be covered for detailed data acquisition. Overall, 5 times as many sanitary inspections were performed on water sources and 4.6 times as many samples analysed in Parishes in zones 1-7 compared in zones 8-10. All household testing was carried out in zones 1-7.

The use of zoning was less widely applied in the other towns, as the smaller numbers of Parishes meant that characterisation was relatively simple. Zoning was used, however, as an initial assessment tool in Soroti, Mbale, Tororo Kabale and Jinja.
5.1 Introduction

The following sections review the water quality and sanitary inspection data for water supplies and household water from the project sites in Uganda. Data from the field studies are summarised and statistical analysis presented for piped water supplies (5.2), protected point water sources (5.3) and household water (5.4).

5.2 Piped Water

Data on piped water quality were collected in all towns, with the exception of Mukono, which had no formal piped network in the town. In seven of the towns the piped water supplies were operated by NW&SC and in the other two towns the piped water supplies were managed by the Municipal authority. In Kabale there were also a number of community-managed gravity-fed piped water systems. The management
arrangements for each town are summarised in Table 5.1 in chronological order of involvement in the programme.

<table>
<thead>
<tr>
<th>Town</th>
<th>Type of piped water supply</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kampala</td>
<td>NW&amp;SC</td>
</tr>
<tr>
<td>Tororo</td>
<td>NW&amp;SC</td>
</tr>
<tr>
<td>Mbale</td>
<td>NW&amp;SC</td>
</tr>
<tr>
<td>Soroti</td>
<td>Municipal</td>
</tr>
<tr>
<td>Masaka</td>
<td>NW&amp;SC</td>
</tr>
<tr>
<td>Mbarara</td>
<td>NW&amp;SC</td>
</tr>
<tr>
<td>Kabale</td>
<td>Municipal &amp; community gravity-schemes</td>
</tr>
<tr>
<td>Jinja</td>
<td>NW&amp;SC</td>
</tr>
<tr>
<td>Entebbe</td>
<td>NW&amp;SC</td>
</tr>
<tr>
<td>Mukono</td>
<td>No formal supply</td>
</tr>
</tbody>
</table>

Table 5.1: Management of piped water supply by urban area

All the piped water systems operated by NW&SC and Municipal authorities came from surface water sources and underwent treatment prior to distribution. Lake Victoria was the source of water for Entebbe, Jinja and Kampala, with all the other towns drawing water from local rivers. Most treatment works used conventional configurations of coagulation-flocculation-settling, rapid sand filtration and disinfection with chlorine, although one of the Kampala treatment works did not use coagulation-flocculation-settling. The community-managed systems used protected springs as the source of water, with no disinfection prior to distribution.

Samples were taken from throughout the distribution systems. Samples were taken at the treatment works (raw water, water from filters and after disinfection) from the Municipal operated supplies, as access was easy to arrange. In the NW&SC supplies, samples were not taken from the treatment works because access to the plants was not easy to arrange. In these supplies, samples were taken from the nearest tap to the works to verify quality of water leaving the plant and sampling was undertaken at the works if it was suspected that a treatment failure had occurred. A similar approach
was also used in relation to the service reservoirs for the same reasons.

Table 5.2 below provides a summary of the numbers of samples taken for microbiological analysis from each town by quarter and year with the number of samples failing to meet the WHO guideline of <1 cfu/100 ml thermotolerant coliforms also recorded. More detailed data are shown in Annex 12.

<table>
<thead>
<tr>
<th>Town</th>
<th>1998</th>
<th>1999</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Kampala</td>
<td>119</td>
<td>125</td>
<td>228</td>
</tr>
<tr>
<td>Mbale</td>
<td>-</td>
<td>-</td>
<td>66</td>
</tr>
<tr>
<td>Soroti</td>
<td>-</td>
<td>-</td>
<td>43</td>
</tr>
<tr>
<td>Tororo</td>
<td>-</td>
<td>-</td>
<td>45</td>
</tr>
<tr>
<td>Kabale</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Masaka</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Mbarara</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Entebbe</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Jinja</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Total</td>
<td>119</td>
<td>125</td>
<td>382</td>
</tr>
</tbody>
</table>

Table 5.2: Piped water samples analysed for thermotolerant coliforms by quarter and year with number of samples failing the WHO Guideline of <1 cfu/100 ml thermotolerant coliforms shown in brackets

The 4th quarter in 1998 shows a peak of samples in Kampala as during this time an outbreak of cholera occurred and testing of water sources increased.

In Uganda the guideline for microbiological quality of drinking water is that given in the WHO Guidelines for Drinking-Water Quality for thermotolerant coliforms. Figure 5.1 below provides a summary of performance of the water supplies expressed as the percentage of samples complying with the guideline.
Figure 5.1: Compliance with Uganda guideline for microbial quality in piped water supply by town

Soroti data includes tests on final water and works tap at treatment works
Table 5.3 provides a summary of performance of the individual water supplies in complying with the guideline. The total compliance is calculated as the total number of samples that met the guideline as a percentage of the total number of samples analysed. Average compliance is the mean of percentage compliance recorded over all quarters for which data are available.

<table>
<thead>
<tr>
<th>Town</th>
<th>Type of supply</th>
<th>Total</th>
<th>Average</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entebbe</td>
<td>NW&amp;SC</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Jinja</td>
<td>NW&amp;SC</td>
<td>78.1</td>
<td>78.6</td>
<td>72.7</td>
<td>88.2</td>
</tr>
<tr>
<td>Kabale</td>
<td>Municipal Council</td>
<td>28.0</td>
<td>33.8</td>
<td>0.0</td>
<td>83.3</td>
</tr>
<tr>
<td>Kampala</td>
<td>NW&amp;SC</td>
<td>97.7</td>
<td>97.3</td>
<td>92.4</td>
<td>99.2</td>
</tr>
<tr>
<td>Masaka</td>
<td>NW&amp;SC</td>
<td>80.6</td>
<td>74.0</td>
<td>60.0</td>
<td>94.1</td>
</tr>
<tr>
<td>Mbale</td>
<td>NW&amp;SC</td>
<td>81.3</td>
<td>82.5</td>
<td>65.2</td>
<td>92.2</td>
</tr>
<tr>
<td>Mbarara</td>
<td>NW&amp;SC</td>
<td>95.7</td>
<td>96.5</td>
<td>89.4</td>
<td>100</td>
</tr>
<tr>
<td>Soroti</td>
<td>Municipal Council</td>
<td>30.8</td>
<td>33.8</td>
<td>14.0</td>
<td>52.3</td>
</tr>
<tr>
<td>Tororo</td>
<td>NW&amp;SC</td>
<td>88.8</td>
<td>88</td>
<td>66.7</td>
<td>96.0</td>
</tr>
</tbody>
</table>

Table 5.3: Compliance performance (expressed as a percentage of samples) for each town

As table 5.3 shows, the Municipal Council water supplies had much lower compliance rates than the NW&SC supplies. The data were analysed using $\chi^2$ to investigate whether this difference was statistically significant, with a null hypothesis that no significant difference would be found. The analysis shows that the difference is significant above the 99% level ($\chi^2 = 528.17$, df = 8, p <0.001) and therefore the null hypothesis is rejected.

5.2.1 Utility supplies

5.2.1.1 Kampala

The Kampala system is more complex than the other supplies, with two water treatment works (both based at Gaba) and 10 major service reservoirs and booster stations in the distribution system. The system has a total of eleven supply zones
based on service reservoirs and treatment works. As shown in table 5.3 above, compliance with the microbiological water quality standard was high in Kampala, with a 97.7% compliance with the WHO guideline from the 1698 samples taken over a two-year period. Compliance improved over the period of sampling as shown in figure 5.1 above. There was a noticeable geographical variation in compliance, however, with compliance being higher in Central, Kawempe and Rubaga Divisions (98.6-99.0%) than in Nakawa (97.7%) and Makindye (95.2%). The levels of contamination when found were usually low (below 20 cfu/100ml and many below 10 cfu/100ml) although a few samples showed contamination up to 66cfu/100ml.

The thermotolerant coliform data for each of the supply zones were analysed to investigate the relationship (if any) to supply zones as a means of identifying whether there was evidence of operational deficiencies in the water supply. Table 5.4 indicates the number of samples and failures found in each supply zone. Supply zones are differentiated into those that are major zones (supplying large parts of the system) and minor (supplying small parts of the system).

<table>
<thead>
<tr>
<th>Supply zone</th>
<th>Zone category</th>
<th>No. samples</th>
<th>No. samples with thermotolerant coliforms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gaba low-level</td>
<td>Major</td>
<td>83</td>
<td>3 (3.6%)</td>
</tr>
<tr>
<td>Muyenga</td>
<td>Major</td>
<td>404</td>
<td>22 (5.4%)</td>
</tr>
<tr>
<td>Gun Hill</td>
<td>Major</td>
<td>873</td>
<td>22 (2.5%)</td>
</tr>
<tr>
<td>Naguru</td>
<td>Major</td>
<td>163</td>
<td>3 (1.8%)</td>
</tr>
<tr>
<td>Rubaga</td>
<td>Major</td>
<td>210</td>
<td>3 (1.4%)</td>
</tr>
<tr>
<td>Mutungo</td>
<td>Major</td>
<td>67</td>
<td>2 (3.0%)</td>
</tr>
<tr>
<td>Buziga booster</td>
<td>Minor</td>
<td>2</td>
<td>0 (0.0%)</td>
</tr>
<tr>
<td>Makindye booster</td>
<td>Minor</td>
<td>13</td>
<td>0 (0.0%)</td>
</tr>
<tr>
<td>Kololo tanks</td>
<td>Minor</td>
<td>7</td>
<td>0 (0.0%)</td>
</tr>
<tr>
<td>Namirembe booster</td>
<td>Minor</td>
<td>111</td>
<td>3 (2.7%)</td>
</tr>
<tr>
<td>Mbuya booster</td>
<td>Minor</td>
<td>36</td>
<td>0 (0.0%)</td>
</tr>
</tbody>
</table>

Table 5.4: Number of contaminated samples by supply zone, Kampala
Although the data show that failures were mostly found on distribution lines served by the Muyenga balancing tanks and Gun Hill service reservoir, this is primarily due to the larger number of samples taken from these areas. The data were analysed using $\chi^2$ to assess whether any significant association was found between zone and the proportion of the samples showing contamination. The null hypothesis was that no significant association would be found. The analysis showed no significant difference ($\chi^2 = 4.88, p = 0.770, df = 8$) and the null hypothesis was accepted. This suggests that thermotolerant coliform presence was not due to problems related to particular service reservoirs or supply lines.

5.2.1.2 Other piped water supplies

There was variation in the quality of water provided by the NW&SC supplies in the remaining towns. As shown in table 5.3, the compliance rate in Mbale was less good than in Kampala and compliance varied during the period of the study. Compliance showed a marked improvement in the last quarter of 1999. Most of the failures in microbiological quality in Mbale are found in Northern Division, an area remote from the supply reservoir and in many parts low-lying and swampy. In Tororo, the compliance rate is generally higher than for Mbale, but was not as good as Kampala.

As shown in table 5.3, no samples from Entebbe showed contamination during the period of study from the water supply and that Mbarara had a compliance rate similar to Kampala. In Masaka, initial good compliance deteriorated over the remaining six months and in Jinja, consistently more samples showed contamination than other NW&SC supplies. Jinja had the worst overall compliance rate. In Soroti, the compliance rate was seen to improve somewhat during the period of study, but remained consistently low. The water leaving the water treatment plant for Soroti was consistently acceptable and none of the 43 samples taken over the period between September 1998 and December 1999 showed any contamination from either the clearwell or the tap at the treatment works.

In Kabale there were no data on the water quality leaving the treatment works and there only a few samples were taken from the distribution system because of the low
level of usage of the Municipal water supply. However, the treatment works was known to be poor and occasionally showed elevated turbidity.

5.2.2 Chlorine data

When samples were taken for microbiological analysis, most were also analysed for free chlorine residual and pH, with a smaller proportion analysed for total chlorine. Figure 5.2 below summarises the data on the percent of samples meeting the WHO (1993) recommended level of 0.2mg/l of free chlorine.
Figure 5.2: Percent compliance with at least 0.2mg/l free chlorine by town and quarter
The data show that the supplies in most towns have not been able to maintain free chlorine residual throughout the distribution system at levels recommended by WHO. The performance in the Kampala supply improved significantly over the period of study, which appears to have resulted both from more frequent cleaning and flushing of the system and from increased dosing of chlorine at the treatment works. However, the increased dosing led to free chlorine at levels above 5.0mg/l, close to the outlet of the works. Of the total 1632 samples tested for free chlorine in Kampala, 782 (52.1%) had concentrations above 0.2 mg/l free chlorine and of the 1632 samples tested for total chlorine 1375 (84.3%) had levels above 0.2mg/l. There was marked variation in free chlorine levels within the Kampala water supply, with compliance with 0.2 mg/l being high in Central and Kawempe Divisions, around 50% in Makindye and very low Nakawa and Rubaga.

The chlorine data were analysed to investigate the relationship (if any) to supply zones in Kampala as a means of identifying whether there was evidence of operational deficiencies in the water supply. Table 5.5 shows that the number of samples, the number with adequate free chlorine and the number with adequate total chlorine found in each supply zone. A figure of 0.2mg/l is taken as the target level for total chlorine residual (which includes chlorine consumed in reactions and represents the dose of chlorine applied) as without at least this concentration, it would be clearly impossible to achieve the free chlorine target concentration.
Table 5.5 shows that in most supply zones, between 25 and 50% of samples lacked an adequate free chlorine residual. Only Gun Hill zone (which serves the central part of the city and receives water direct from the treatment plant) achieved even 60% compliance with the free chlorine residual target. The Gaba low-level zone and Muyenga zone show samples failing to comply with the total chlorine target,
suggesting that chlorination was at times interrupted at the treatment works. The minor zones served by boosters show a marked variation in compliance, although the number of samples tested was small, thus these data need to be treated with some caution. Compliance with at least 0.2mg/l of total chlorine is generally much higher.

Data for chlorine in the other utility piped water supplies are summarised in table 5.6 below. This shows that the percentage of samples with at least 0.2mg/l free chlorine residual is generally below 50%. The overall percentage of samples with at least 0.2mg/l free chlorine was only 42.1%. In Entebbe the percentage of samples with at least 0.2mg/l free chlorine is much higher than the other supplies. In general, the low levels of free chlorine indicate that the dosing was largely insufficient at the treatment works and further chlorine was lost in distribution.

<table>
<thead>
<tr>
<th>Town</th>
<th>No. tests free Cl</th>
<th>No. &gt;0.2mg/l</th>
<th>No. tests total Cl</th>
<th>No. &gt;0.2mg/l</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entebbe</td>
<td>22</td>
<td>18 (81.8%)</td>
<td>26</td>
<td>22 (84.6%)</td>
</tr>
<tr>
<td>Jinja</td>
<td>63</td>
<td>3 (4.8%)</td>
<td>38</td>
<td>7 (18.4%)</td>
</tr>
<tr>
<td>Kabale</td>
<td>16</td>
<td>14 (87.5%)</td>
<td>16</td>
<td>16 (100%)</td>
</tr>
<tr>
<td>Masaka</td>
<td>52</td>
<td>4 (7.7%)</td>
<td>42</td>
<td>1 (2.4%)</td>
</tr>
<tr>
<td>Mbale</td>
<td>209</td>
<td>88 (42.1%)</td>
<td>133</td>
<td>111 (83.5%)</td>
</tr>
<tr>
<td>Mbarara</td>
<td>114</td>
<td>0 (0%)</td>
<td>114</td>
<td>22 (19.3%)</td>
</tr>
<tr>
<td>Soroti</td>
<td>134</td>
<td>56 (41.8%)</td>
<td>62</td>
<td>56 (90.3%)</td>
</tr>
<tr>
<td>Tororo</td>
<td>107</td>
<td>17 (15.9%)</td>
<td>98</td>
<td>31 (31.6%)</td>
</tr>
</tbody>
</table>

Table 5.6: Number and percent of samples meeting chlorine targets by town excluding Kampala

The Soroti supply shows good maintenance of free chlorine within the supply, which is surprising given the evidence of microbiological contamination. Such high rates of compliance would suggest that repeated ingress along the distribution mains occurred. The rates in Kabale are very variable, although the very small number of samples prevents any strong conclusions from being drawn.
In all samples taken from the piped water supplies, the pH was acceptable for chlorination (below 8.5) and in most towns generally between 6.5 and 8.5. Turbidity was also generally good with very few (below 10) samples showing turbidity above 5 NTU. Those exceeding this figure were found in Kabale. The water appearance in most samples was clear, with occasional samples in Mbale and Kabale being noted as cloudy or coloured.

5.2.3 Sanitary inspection data

As noted in section 3.5.4 sanitary inspection forms for piped water supply were modified during the period of study. Only those based on the Parish-wide format are reported here. Table 5.7 shows the minimum, median and maximum sanitary risk score.

<table>
<thead>
<tr>
<th>Town</th>
<th>No. Inspections</th>
<th>Median</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entebbe</td>
<td>12</td>
<td>30</td>
<td>10</td>
<td>50</td>
</tr>
<tr>
<td>Jinja</td>
<td>21</td>
<td>20</td>
<td>0</td>
<td>90</td>
</tr>
<tr>
<td>Kabale</td>
<td>18</td>
<td>25</td>
<td>0</td>
<td>50</td>
</tr>
<tr>
<td>Kampala</td>
<td>852</td>
<td>20</td>
<td>0</td>
<td>90</td>
</tr>
<tr>
<td>Masaka</td>
<td>20</td>
<td>20</td>
<td>0</td>
<td>70</td>
</tr>
<tr>
<td>Mbale</td>
<td>105</td>
<td>30</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>Mbarara</td>
<td>28</td>
<td>30</td>
<td>0</td>
<td>90</td>
</tr>
<tr>
<td>Soroti</td>
<td>157</td>
<td>20</td>
<td>0</td>
<td>70</td>
</tr>
<tr>
<td>Tororo</td>
<td>77</td>
<td>20</td>
<td>0</td>
<td>70</td>
</tr>
</tbody>
</table>

Table 5.7: Sanitary inspection data for piped water supplies

The median sanitary risk score shows variation between the towns and a Kruskal-Wallis test was performed to analyse whether there was any significant difference in median risk values. The null hypothesis was that no significant difference would be found. The analysis showed that there was a significant difference between the towns ($\chi^2 = 39.63$, df = 8, p<0.001) and the null hypothesis was rejected.

The frequency reporting of the individual risk factors for each town are shown in figure 5.3 below. Overall, reporting of faults close to the point of sampling is
generally higher than for faults related to the overall supply design, construction and operation and maintenance. There is an average reporting rate for these risks (questions 1-5) of 34.4% compared to 17.2% for supply risks (questions 6-10). However, there is significant variation between the different towns, although some differences in percent reporting may be somewhat exaggerated because of the differences in the number of inspections performed.
Figure 5.3: Percent reporting of individual risk factors in piped water by town

1 = Tap lacks support
2 = Water collects around tap
3 = Area uphill of tap eroded
4 = Pipe exposed close to tap
5 = Human excreta within 10m
6 = Sewer within 30m
7 = Discontinuity within previous 7 days
8 = Signs of leakage within Parish
9 = Community report pipe break in last week
10 = Main exposed in Parish
The frequency of reporting of individual risk factors was analysed to see whether any differences were noted between NW&SC supplies and Municipal Council run supplies to assess whether there were any significant differences that would reflect operational practice. A dummy coded binary variable was defined in SPSS for water supply management type (1 = NW&SC, 2 = Municipal). The data were analysed using $\chi^2$, with the null hypotheses that no significant differences would be found. The results of these analyses are shown in table 5.8.

<table>
<thead>
<tr>
<th>Risk factor</th>
<th>Supply type</th>
<th>No</th>
<th>Yes</th>
<th>$\chi^2$, p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tap lacks support</td>
<td>NWSC</td>
<td>544</td>
<td>571</td>
<td>11.78, 0.001</td>
</tr>
<tr>
<td></td>
<td>Municipal</td>
<td>61</td>
<td>114</td>
<td></td>
</tr>
<tr>
<td>Surface water around tap</td>
<td>NWSC</td>
<td>725</td>
<td>390</td>
<td>51.55, &lt;0.001</td>
</tr>
<tr>
<td></td>
<td>Municipal</td>
<td>64</td>
<td>111</td>
<td></td>
</tr>
<tr>
<td>Area uphill of tap eroded</td>
<td>NWSC</td>
<td>738</td>
<td>377</td>
<td>31.94, &lt;0.001</td>
</tr>
<tr>
<td></td>
<td>Municipal</td>
<td>153</td>
<td>22</td>
<td></td>
</tr>
<tr>
<td>Pipe exposed close to tap</td>
<td>NWSC</td>
<td>807</td>
<td>308</td>
<td>0.07</td>
</tr>
<tr>
<td></td>
<td>Municipal</td>
<td>125</td>
<td>50</td>
<td>0.795</td>
</tr>
<tr>
<td>Human excreta within 10m of tap</td>
<td>NWSC</td>
<td>857</td>
<td>258</td>
<td>14.86</td>
</tr>
<tr>
<td></td>
<td>Municipal</td>
<td>157</td>
<td>18</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Sewer within 10m of tap</td>
<td>NWSC</td>
<td>930</td>
<td>185</td>
<td>2.38</td>
</tr>
<tr>
<td></td>
<td>Municipal</td>
<td>154</td>
<td>21</td>
<td>0.123</td>
</tr>
<tr>
<td>Discontinuity within previous 7 days</td>
<td>NWSC</td>
<td>927</td>
<td>188</td>
<td>8.99</td>
</tr>
<tr>
<td></td>
<td>Municipal</td>
<td>161</td>
<td>14</td>
<td>0.003</td>
</tr>
<tr>
<td>Sign of leakage within Parish</td>
<td>NWSC</td>
<td>745</td>
<td>370</td>
<td>7.44</td>
</tr>
<tr>
<td></td>
<td>Municipal</td>
<td>135</td>
<td>40</td>
<td>0.006</td>
</tr>
<tr>
<td>Community report pipe break in prev.</td>
<td>NWSC</td>
<td>1045</td>
<td>70</td>
<td>1.29</td>
</tr>
<tr>
<td>week</td>
<td>Municipal</td>
<td>160</td>
<td>15</td>
<td>0.256</td>
</tr>
<tr>
<td>Main pipe exposed in Parish</td>
<td>NWSC</td>
<td>960</td>
<td>155</td>
<td>4.48</td>
</tr>
<tr>
<td></td>
<td>Municipal</td>
<td>140</td>
<td>35</td>
<td>0.034</td>
</tr>
</tbody>
</table>

Table 5.8: Results of $\chi^2$ analysis of comparison of risk factor reporting from sanitary inspection by supply management type

The analysis showed that for seven of the risk factors a significant difference in reporting was found and the null hypotheses rejected. No significant difference was seen in reporting for the remaining three risk factors and the null hypotheses were
accepted.

5.2.4 Relationships between risk factors, chlorine and microbiological quality

The microbiological quality, chlorine residual and sanitary inspection data were analysed to assess whether significant associations existed.

5.2.4.1 Association between chlorine data and microbiological data

The microbiological and chlorine data were analysed to test whether there were associations between the presence of less than 0.2mg/l of free or total chlorine and microbial contamination. The null hypotheses were that no associations would exist.

The data for microbiological quality, free chlorine and total chlorine were transformed into the three dummy binary categorical variables as described in section 3.10. The data were analysed using $\chi^2$. To ensure comparability across all towns, water quality data were selected when samples could be related to the Parish-wide sanitary inspection. Data were analysed for the full data set of nine towns (including Entebbe) and for each individual town (excluding Entebbe where no contamination occurred). An example of the analysis is shown below in table 5.9 (for data from all supplies). The results of analyses for each individual town are summarised in table 5.10 and the detailed analysis is shown in Annex 13.

<table>
<thead>
<tr>
<th>Analysis</th>
<th>Contamination found</th>
<th>$\chi^2$, p</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Adequate free chlorine</td>
<td>No</td>
<td>1108</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>219</td>
</tr>
<tr>
<td>Adequate total chlorine</td>
<td>No</td>
<td>597</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>187</td>
</tr>
</tbody>
</table>

Table 5.9: Example of analysis of chlorine and presence of thermotolerant coliforms (all supplies)
Table 5.10: Analysis of association between chlorine residuals and presence of thermotolerant coliforms

* Could not be calculated for Mbarara because no samples had adequate free chlorine residual

The analyses shown in the tables show that for the analysis of data from all towns there is an association significant at the 99% confidence level between the absence of adequate free chlorine and the presence of thermotolerant coliforms and the null hypothesis is rejected. However, when analysed individually there is variation in the result of analysis between the towns. Only in Mbale was the association significant to the 99% confidence level and in Kampala an association significant to the 95% confidence level.

The analysis of data from all towns showed that there was an association significant at the 99% confidence level between lack of adequate total chlorine and thermotolerant coliform presence and the null hypothesis was rejected. When analysed individually again variation is seen between the towns. The analysis showed results significant at the 99% confidence level for Kampala and Mbarara; Kabale and Mbale showed an association significant at the 95% confidence level. No significant associations were found for analysis of data from the other towns.
5.2.4.2 Relationships to sanitary risks

The sanitary inspection data were analysed to see whether there was a relationship between overall risk score (expressed as a percentage) and the number of thermotolerant coliforms found. The null hypothesis was that no relationship would exist between overall sanitary risk score and number of thermotolerant coliforms. This was analysed using the Spearman’s rank correlation, following the recommendation of Tillett et al. (2001).

When analysing the aggregated data from all towns, there is a significant correlation between the risk score and number of thermotolerant coliform present ($Rs = 0.089$, $p = 0.01$) and thus the null hypothesis is rejected. This relationship is shown in figure 5.4 below, where 200 is a nominal default value assigned for results of too numerous to count (TNTC). Although the correlation statistic is significant, the low value of $Rs$ and the spread of data around the trend line indicate that the relationship is not particularly strong, despite the significance of the result.

![Figure 5.4: Relationship between sanitary total score and contamination for piped water supplies](image)

**Figure 5.4: Relationship between sanitary total score and contamination for piped water supplies**

NB: 200 is a default value for TNTC

The data for NW&SC supplies and Municipal supplies were analysed separately using the same correlation statistic and null hypothesis. The analysis showed that significant correlations were found for both the NW&SC supplies ($Rs = 0.1$, $p = 0.01$) and the Municipal run supplies ($Rs = 0.26$, $p = 0.01$) and the null hypotheses were rejected.
However, the Rs values are again low, suggesting that the relationship is not strong.

The data indicate that median risk score was higher when contamination was found (30%) compared to when contamination was absent (20%). This is shown in the box plot in Figure 5.5. In the box plot the outline of the box represents the inter-quartile range (25-75%), the solid line shows the median and the whiskers are lines that extend from the box to the highest and lowest values, excluding outliers (Helsel and Hirsch 1992).

<table>
<thead>
<tr>
<th>Sanitary risk (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
</tr>
<tr>
<td>10</td>
</tr>
<tr>
<td>20</td>
</tr>
<tr>
<td>30</td>
</tr>
<tr>
<td>40</td>
</tr>
<tr>
<td>50</td>
</tr>
<tr>
<td>60</td>
</tr>
<tr>
<td>70</td>
</tr>
<tr>
<td>80</td>
</tr>
<tr>
<td>90</td>
</tr>
<tr>
<td>100</td>
</tr>
</tbody>
</table>

No Yes

Thermotolerant coliforms present

Figure 5.5: Boxplots showing median, inter-quartile range and range of sanitary risk score when thermotolerant coliforms were found compared to when they were absent piped in water supplies

The data were analysed to see whether there was a significant difference in the median value. As the data were not normally distributed, a Kruskal-Wallis test was performed. The null hypothesis was that no significant difference in median risk when contamination was found compared to when it was absent would be found. The analysis showed that there was a difference in median risk between the two groups,
significant at the 99% confidence level ($\chi^2 = 8.88$, df = 1, p = 0.003) and the null hypothesis was rejected.

5.2.4.3 Relationships with sanitary risk factors

The microbiological water quality and sanitary inspection data were analysed to assess whether any associations existed between risk factors and the presence of contamination. The first stage in this analysis was to look at the difference in reporting of the different factors between when thermotolerant coliforms were absent and when they were present. These data is summarised for the aggregated data for all towns and for each individual town in table 5.11 below.
<table>
<thead>
<tr>
<th>Town</th>
<th>Taps lack support</th>
<th>Water collects around tap</th>
<th>Area uphill of tap eroded</th>
<th>Pipe exposed close to tap</th>
<th>Human excreta within 10m of tap</th>
<th>Sewer within 30m of tap</th>
<th>Discontinuity in previous 10 days</th>
<th>Signs of leakage in Parish</th>
<th>Community report pipe breaks in last week</th>
<th>Main pipe exposed in Parish</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entebbe</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Jinja</td>
<td>-3</td>
<td>+25</td>
<td>-6</td>
<td>+19</td>
<td>+19</td>
<td>-2</td>
<td>+48</td>
<td>+27</td>
<td>+33</td>
<td>+16</td>
</tr>
<tr>
<td>Kabale</td>
<td>+21</td>
<td>+7</td>
<td>-50</td>
<td>+7</td>
<td>0</td>
<td>+11</td>
<td>+7</td>
<td>+36</td>
<td>+43</td>
<td>+7</td>
</tr>
<tr>
<td>Kampala</td>
<td>+16</td>
<td>+18</td>
<td>-5</td>
<td>-3</td>
<td>+2</td>
<td>+9</td>
<td>+11</td>
<td>+3</td>
<td>+4</td>
<td>+14</td>
</tr>
<tr>
<td>Masaka</td>
<td>+37</td>
<td>+57</td>
<td>+15</td>
<td>+42</td>
<td>+17</td>
<td>-2</td>
<td>+2</td>
<td>+17</td>
<td>-10</td>
<td>-2</td>
</tr>
<tr>
<td>Mbale</td>
<td>+10</td>
<td>+1</td>
<td>+19</td>
<td>+9</td>
<td>+13</td>
<td>+4</td>
<td>-2</td>
<td>+3</td>
<td>0</td>
<td>+5</td>
</tr>
<tr>
<td>Mbarara</td>
<td>+2</td>
<td>-6</td>
<td>+7</td>
<td>-9</td>
<td>+66</td>
<td>+16</td>
<td>+31</td>
<td>+8</td>
<td>-9</td>
<td>-18</td>
</tr>
<tr>
<td>Soroti</td>
<td>+16</td>
<td>+12</td>
<td>+8</td>
<td>+11</td>
<td>+9</td>
<td>-6</td>
<td>-5</td>
<td>+11</td>
<td>-2</td>
<td>+13</td>
</tr>
<tr>
<td>Tororo</td>
<td>+5</td>
<td>+10</td>
<td>-6</td>
<td>+11</td>
<td>+2</td>
<td>+4</td>
<td>+1</td>
<td>-14</td>
<td>-10</td>
<td>+14</td>
</tr>
<tr>
<td>Overall</td>
<td>+14</td>
<td>+27</td>
<td>-12</td>
<td>+4</td>
<td>0</td>
<td>0</td>
<td>+1</td>
<td>-3</td>
<td>+5</td>
<td>+11</td>
</tr>
</tbody>
</table>

Table 5.11 Difference in percentage reporting between when no contamination detected and contamination detected in piped water by Town
The score in each cell in table 5.11 shows the numerical difference between the percent reporting of the factor between the two conditions. A positive figure indicating that the factor was reported more frequently when contamination was found than when it was absent and a negative figure that the factor was less frequently reported when contamination was found than when it was absent.

The data were analysed to investigate whether there were associations between the presence of particular risk factors and contamination being found. The individual risk factors provide binary categories scoring either 1 or 0. The dummy coded binary variable defined in section 3.10 was used and the data were analysed in a contingency table using odds ratios (the ratio of the probability of obtaining a score of 1 divided by the probability of obtaining a score of 0). An odds ratio (OR) exceeding 1 indicates that a positive relationship exists between the factor and the outcome and a score of less than one, that a negative relationship exists.

The null hypothesis was that no difference in reporting of individual risk factors would be found between when thermotolerant coliforms were present and when they were absent. The results of this analysis when taking data from all towns is shown in table 5.12 below. This table also provides the confidence interval (CI) for each factor, which is the range of values representing the computed 95% confidence level of the calculated odds ratio.
<table>
<thead>
<tr>
<th>Risk factor</th>
<th>Factor present</th>
<th>Thermotolerant coliforms present</th>
<th>Statistics</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>p</td>
</tr>
<tr>
<td>Tapstands</td>
<td>Yes</td>
<td>140</td>
<td>532</td>
<td>73</td>
<td>545</td>
</tr>
<tr>
<td>lack support</td>
<td>No</td>
<td>73</td>
<td>545</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surface water</td>
<td>Yes</td>
<td>130</td>
<td>371</td>
<td>83</td>
<td>706</td>
</tr>
<tr>
<td>around tap</td>
<td>No</td>
<td>83</td>
<td>706</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Area uphill of</td>
<td>Yes</td>
<td>41</td>
<td>358</td>
<td>172</td>
<td>719</td>
</tr>
<tr>
<td>tap eroded</td>
<td>No</td>
<td>172</td>
<td>719</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Piped exposed</td>
<td>Yes</td>
<td>65</td>
<td>293</td>
<td>148</td>
<td>784</td>
</tr>
<tr>
<td>close to tap</td>
<td>No</td>
<td>148</td>
<td>784</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Human excreta</td>
<td>Yes</td>
<td>46</td>
<td>230</td>
<td>167</td>
<td>847</td>
</tr>
<tr>
<td>&lt;10m of tap</td>
<td>No</td>
<td>167</td>
<td>847</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sewer &lt;30m of</td>
<td>Yes</td>
<td>34</td>
<td>172</td>
<td>179</td>
<td>905</td>
</tr>
<tr>
<td>tap</td>
<td>No</td>
<td>179</td>
<td>905</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Discontinuity &lt;7 days</td>
<td>Yes</td>
<td>36</td>
<td>166</td>
<td>177</td>
<td>911</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>177</td>
<td>911</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Signs of leaks in Parish</td>
<td>Yes</td>
<td>62</td>
<td>348</td>
<td>151</td>
<td>729</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>151</td>
<td>729</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Community report pipe break &lt;10 days</td>
<td>Yes</td>
<td>23</td>
<td>62</td>
<td>190</td>
<td>1015</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>190</td>
<td>1015</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Main pipe exposed in Parish</td>
<td>Yes</td>
<td>52</td>
<td>138</td>
<td>161</td>
<td>939</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>161</td>
<td>939</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 5.12: Contingency table analysis of risk factors and contamination for all piped water supplies

The analysis showed that four variables show a positive association significant at the 99% level between their presence and the presence of thermotolerant coliforms and for these factors the null hypotheses were rejected. Four factors showed no significant association with the presence of thermotolerant coliforms and two had a negative association with contamination and for these four factors the null hypotheses are accepted.

The data for NW&SC supplies and Municipal supplies were analysed separately because the larger number of NW&SC supplies could have biased the analysis of data from all the towns and because different risk factors may have been important within the two different types of supply. These analyses used the same null hypotheses as for the analysis of the full data set and the results are presented in tables 5.13 and 5.14 below.
<table>
<thead>
<tr>
<th>Risk factor</th>
<th>Factor present</th>
<th>Thermotolerant coliforms present</th>
<th>Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yes</td>
<td>No</td>
<td>p</td>
</tr>
<tr>
<td>Tapstands lack support</td>
<td>Yes</td>
<td>52</td>
<td>519</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>35</td>
<td>509</td>
</tr>
<tr>
<td>Surface water around tap</td>
<td>Yes</td>
<td>46</td>
<td>344</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>41</td>
<td>684</td>
</tr>
<tr>
<td>Area uphill of tap eroded</td>
<td>Yes</td>
<td>25</td>
<td>352</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>62</td>
<td>676</td>
</tr>
<tr>
<td>Piped exposed close to tap</td>
<td>Yes</td>
<td>27</td>
<td>281</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>60</td>
<td>747</td>
</tr>
<tr>
<td>Human excreta &lt;10m of tap</td>
<td>Yes</td>
<td>30</td>
<td>228</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>57</td>
<td>800</td>
</tr>
<tr>
<td>Sewer &lt;30m of tap</td>
<td>Yes</td>
<td>20</td>
<td>165</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>67</td>
<td>863</td>
</tr>
<tr>
<td>Discontinuity &lt;7 days</td>
<td>Yes</td>
<td>27</td>
<td>161</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>60</td>
<td>867</td>
</tr>
<tr>
<td>Signs of leaks in Parish</td>
<td>Yes</td>
<td>29</td>
<td>341</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>58</td>
<td>687</td>
</tr>
<tr>
<td>Community report pipe break &lt;10days</td>
<td>Yes</td>
<td>11</td>
<td>59</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>76</td>
<td>969</td>
</tr>
<tr>
<td>Main pipe exposed in Parish</td>
<td>Yes</td>
<td>22</td>
<td>133</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>65</td>
<td>895</td>
</tr>
</tbody>
</table>

Table 5.13: Contingency table analysis of risk factors and contamination for NW&SC piped water supplies

In the NW&SC supplies, three risk factors have a positive relationship significant at the 99% level and one is significant at the 95% level. For these factors the null hypotheses are rejected. For the other factors, the null hypotheses were accepted. In the Municipal supplies, no risk factors are significant at the 99% level, but tapstands lacking support and main exposed in the Parish are significant at the 95% level and only for these factors were the null hypothesis rejected.
<table>
<thead>
<tr>
<th>Risk factor</th>
<th>Factor present</th>
<th>Thermotolerant coliforms present</th>
<th>Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Tapstands lack support</td>
<td>Yes</td>
<td>88</td>
<td>26</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>38</td>
<td>23</td>
</tr>
<tr>
<td>Surface water around tap</td>
<td>Yes</td>
<td>84</td>
<td>27</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>42</td>
<td>22</td>
</tr>
<tr>
<td>Area uphill of tap eroded</td>
<td>Yes</td>
<td>16</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>110</td>
<td>43</td>
</tr>
<tr>
<td>Piped exposed close to tap</td>
<td>Yes</td>
<td>38</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>88</td>
<td>37</td>
</tr>
<tr>
<td>Human excreta &lt;10m of tap</td>
<td>Yes</td>
<td>16</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>110</td>
<td>47</td>
</tr>
<tr>
<td>Sewer &lt;30m of tap</td>
<td>Yes</td>
<td>14</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>112</td>
<td>42</td>
</tr>
<tr>
<td>Discontinuity &lt;7 days</td>
<td>Yes</td>
<td>9</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>117</td>
<td>44</td>
</tr>
<tr>
<td>Signs of leaks in Parish</td>
<td>Yes</td>
<td>33</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>93</td>
<td>42</td>
</tr>
<tr>
<td>Community report pipe break &lt;10days</td>
<td>Yes</td>
<td>12</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>114</td>
<td>46</td>
</tr>
<tr>
<td>Main pipe exposed in Parish</td>
<td>Yes</td>
<td>30</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>96</td>
<td>44</td>
</tr>
</tbody>
</table>

Table 5.14: Contingency table analysis of risk factors and contamination for Municipal run piped water supplies

In order to model the influence of different risk factors in causing contamination, the microbiological water quality and sanitary inspection data were analysed using logistic regression. This allows regression analysis of discrete response variables by transforming probabilities into continuous variables with an infinite number of negative and positive values possible (Helsel and Hirsch, 1992).

The models developed are shown in table 5.15. For the models developed aggregated data from all towns, only factors with odds ratios significant at the 95% level were included: lack of tapstand support, surface water collecting around the tap, erosion of the area uphill of the tap and the main exposed in the Parish. Four other factors were forced into the model – sewer proximity, discontinuity, signs of leakage and community reports of pipe breaks - given the plausibility of their influence on contamination. A further dummy binary category was defined to describe the
management of the supply, with numerical values assigned to NW&SC and Municipal run supplies.

In the model developed for only NW&SC supplies the factors included were surface water collecting around the tap, human excreta within 10m of the tap, discontinuity within the previous 7 days, community reports of pipe breaks within the previous week and the main exposed in the Parish. Two other factors were forced into the model – sewer proximity and signs of leakage - given the plausibility of their influence on contamination. For the Municipal supplies, two factors significant at the 90% level were included in the model: human excreta within 10m and signs of leakage. Three other factors – sewer proximity, discontinuity and community reports of pipe breaks were forced into the model.

<table>
<thead>
<tr>
<th>Model</th>
<th>Model log estimate</th>
<th>Variables</th>
<th>Variable coefficient</th>
<th>SE</th>
<th>Wald</th>
<th>df</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>All towns</td>
<td>776.78</td>
<td>Constant</td>
<td>2.31</td>
<td>0.4</td>
<td>33.53</td>
<td>1</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tapstand lacks support</td>
<td>-0.36</td>
<td>0.2</td>
<td>3.07</td>
<td>1</td>
<td>0.08</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Surface water around tap</td>
<td>-0.7</td>
<td>0.2</td>
<td>11.76</td>
<td>1</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Erosion uphill of tap</td>
<td>0.47</td>
<td>0.23</td>
<td>4.18</td>
<td>1</td>
<td>0.041</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Discontinuity in last 7 days</td>
<td>-0.71</td>
<td>0.24</td>
<td>8.64</td>
<td>1</td>
<td>0.003</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Main exposed in Parish</td>
<td>-0.85</td>
<td>0.23</td>
<td>13.34</td>
<td>1</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Supply management</td>
<td>-3.29</td>
<td>0.22</td>
<td>226.99</td>
<td>1</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>NW&amp;SC supplies</td>
<td>580.19</td>
<td>Constant</td>
<td>-0.77</td>
<td>0.31</td>
<td>6.13</td>
<td>1</td>
<td>0.013</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Surface water around tap</td>
<td>-0.75</td>
<td>0.23</td>
<td>10.78</td>
<td>1</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Discontinuity in last 7 days</td>
<td>-0.83</td>
<td>0.25</td>
<td>10.96</td>
<td>1</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Main exposed in Parish</td>
<td>-0.78</td>
<td>0.27</td>
<td>8.37</td>
<td>1</td>
<td>0.004</td>
</tr>
<tr>
<td>MCWS supplies</td>
<td>198.67</td>
<td>Constant</td>
<td>0.33</td>
<td>0.28</td>
<td>1.38</td>
<td>1</td>
<td>0.24</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tapstand lacks support</td>
<td>0.73</td>
<td>0.35</td>
<td>4.35</td>
<td>1</td>
<td>0.037</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Main exposed in Parish</td>
<td>1.03</td>
<td>0.52</td>
<td>3.89</td>
<td>1</td>
<td>0.048</td>
</tr>
</tbody>
</table>

Table 5.15: Logistic regression model of risk factors and contamination events
In all the models developed, the log estimate goodness of fit measure is significant and therefore the null hypotheses were rejected. Of all the models developed, the one for all towns has the best model fit as shown by the model log estimated goodness of fit measure. This is a 6-factor model, which reflects the overall range of influences of sanitary risk factors on contamination. Type of supply is in the final model, with a large coefficient that is significant above the 99% confidence level, which indicates that differences in supply management have a significant effect on water quality.

The model for NW&SC supplies has a less good fit than for the model for all towns. There are only three factors in the models. The Municipal supplies have only a two-factor model and the goodness of fit is less good. This analysis shows that taking overall sets of data allows more comprehensive models of risk factor and water quality interactions to be described and that overall management is likely to influence water quality control. In all the models it is clear that both supply operation and localised factors are important in leading to contamination and that when the data for all towns is analysed, local risks rather than supply risks predominate.

For the final stage of analysis, the microbiological water quality, sanitary inspection and chlorine data were combined to assess the relationships between the three factors. Logistic regression models were developed and are summarised in table 5.16.
<table>
<thead>
<tr>
<th>Model</th>
<th>Model log estimate</th>
<th>Variables</th>
<th>Variable coefficient</th>
<th>SE</th>
<th>Wald</th>
<th>df</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>All towns</td>
<td>736.76</td>
<td>Constant</td>
<td>1.05</td>
<td>0.43</td>
<td>6.13</td>
<td>1</td>
<td>0.013</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Surface water around tap</td>
<td>-0.73</td>
<td>0.20</td>
<td>13.79</td>
<td>1</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Main exposed in Parish</td>
<td>-0.69</td>
<td>0.24</td>
<td>8.15</td>
<td>1</td>
<td>0.004</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Discontinuity in last 7 days</td>
<td>-0.45</td>
<td>0.25</td>
<td>3.25</td>
<td>1</td>
<td>0.072</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Supply management</td>
<td>-3.33</td>
<td>0.22</td>
<td>210.32</td>
<td>1</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Adequate free chlorine</td>
<td>0.98</td>
<td>0.25</td>
<td>15.98</td>
<td>1</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Adequate total chlorine</td>
<td>0.82</td>
<td>0.20</td>
<td>16.87</td>
<td>1</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>NW&amp;SC supplies</td>
<td>530.54</td>
<td>Constant</td>
<td>-1.54</td>
<td>0.38</td>
<td>16.27</td>
<td>1</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Surface water around tap</td>
<td>-0.68</td>
<td>0.25</td>
<td>7.74</td>
<td>1</td>
<td>0.005</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Excreta within 10m</td>
<td>-0.47</td>
<td>0.26</td>
<td>3.21</td>
<td>1</td>
<td>0.073</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Discontinuity in last 7 days</td>
<td>-0.64</td>
<td>0.27</td>
<td>5.8</td>
<td>1</td>
<td>0.016</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Main exposed in Parish</td>
<td>-0.54</td>
<td>0.28</td>
<td>3.61</td>
<td>1</td>
<td>0.058</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Adequate total chlorine</td>
<td>1.63</td>
<td>0.24</td>
<td>45.56</td>
<td>1</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>MCWS supplies</td>
<td>198.67</td>
<td>Constant</td>
<td>1.31</td>
<td>0.57</td>
<td>5.29</td>
<td>1</td>
<td>0.021</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tapstands lack support</td>
<td>-0.88</td>
<td>0.37</td>
<td>5.61</td>
<td>1</td>
<td>0.018</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Main exposed in Parish</td>
<td>-0.99</td>
<td>0.53</td>
<td>3.44</td>
<td>1</td>
<td>0.064</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Adequate free chlorine</td>
<td>1.2</td>
<td>0.39</td>
<td>9.33</td>
<td>1</td>
<td>0.002</td>
</tr>
</tbody>
</table>

Table 5.16: Logistic regression models of microbiological water quality, sanitary inspection and chlorine data

For the models developed for data from all towns and for NW&SC supplies only, the model log estimate goodness of fit is slightly lower than for the models developed solely on sanitary risks, but remains the same for the model Municipal supplies. These models show little change from the sanitary inspection-based models apart from the inclusion of the chlorine residuals in the final model. The model for all towns includes both adequate free and total chlorine, the NW&SC model only includes adequate total chlorine and the Municipal supplies models include only free chlorine, which reflects...
the findings of analysis in section 5.2.4.1.

5.2.5 Community-managed piped supplies, Kabale

In Kabale, there were four community-managed gravity fed piped water systems. These were supplied from protected springs located in the hills around the town and served the majority of the population, primarily through public taps. Although the communities served were expected to manage the system, in practice the Kabale Town Council, through the Urban Water Office and supporting agencies (Directorate of Water Development and various donor organisations) undertook a significant amount of work. This took the form of providing (at cost) materials for repair of the systems and in maintenance. They were also involved in the design of new projects.

Samples were taken throughout the system and included the source of water. However, the majority of the sources had no outlet from which a sample could be taken and therefore the storage tank, or first tap if this was above the storage tank, was the usual first sampling point that could be accessed.

The water quality of the gravity fed systems was generally good as summarised in table 5.17 below and in more detail in Annex 14. Only one result of 'too numerous to count' (TNTC) was obtained. The turbidity in all samples taken was less than 5 NTU and the appearance was clear in all samples.

<table>
<thead>
<tr>
<th>System</th>
<th>No. samples</th>
<th>Minimum cfu/100ml</th>
<th>Maximum cfu/100ml</th>
<th>Median cfu/100ml</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bugongi A</td>
<td>18</td>
<td>0</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>Bugongi B</td>
<td>8</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Rutooma</td>
<td>10</td>
<td>0</td>
<td>TNTC</td>
<td>4.5</td>
</tr>
<tr>
<td>Nyakaharo/Karubanda</td>
<td>22</td>
<td>0</td>
<td>39</td>
<td>1</td>
</tr>
<tr>
<td>All supplies</td>
<td>58</td>
<td>0</td>
<td>TNTC</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 5.17: Results of analysis of thermotolerant coliform water from gravity-fed schemes Kabale

The storage tanks in the systems showed proportionally more contamination than
samples taken from the taps and the TNTC result was obtained from a storage tank. As shown in table 5.18 below, the median contamination for storage tanks was 9 cfu/100ml and that for taps as 2 cfu/100ml.

<table>
<thead>
<tr>
<th>System</th>
<th>No. samples</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Median</th>
</tr>
</thead>
<tbody>
<tr>
<td>Storage tanks</td>
<td>10</td>
<td>0</td>
<td>TNTC</td>
<td>9</td>
</tr>
<tr>
<td>Taps</td>
<td>48</td>
<td>0</td>
<td>39</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 5.18: Results of analysis of thermotolerant coliforms in water from storage tanks and taps in gravity-fed schemes Kabale

Sanitary inspections were performed on the distribution system, including storage tanks and is summarised in table 5.19 below. These data show that overall sanitary risks were generally low for all gravity-fed supplies, although there is variation between the different supplies. This indicates that operation and maintenance performance varied between the different systems.

<table>
<thead>
<tr>
<th>System</th>
<th>No. inspections</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Median</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bugongi A</td>
<td>8</td>
<td>0</td>
<td>25</td>
<td>16</td>
</tr>
<tr>
<td>Bugongi B</td>
<td>5</td>
<td>0</td>
<td>34</td>
<td>0</td>
</tr>
<tr>
<td>Rutooma</td>
<td>6</td>
<td>0</td>
<td>25</td>
<td>4</td>
</tr>
<tr>
<td>Nyakaharo/</td>
<td>7</td>
<td>16</td>
<td>33</td>
<td>25</td>
</tr>
<tr>
<td>Karubanda</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All supplies</td>
<td>26</td>
<td>0</td>
<td>34</td>
<td>16</td>
</tr>
</tbody>
</table>

Table 5.19: Sanitary risk score data for the gravity-fed schemes, Kabale

The water quality and sanitary inspection data were analysed to investigate relationships. Overall, there was little correlation between contamination and sanitary risk score for maximum and median contamination.
The dummy coded variables described in section 3.10 for presence or absence of thermotolerant coliforms and contamination exceeding 10 cfu/100ml were used in this analysis. The data for each risk factor and water quality dummy coded variables were analysed using odds ratios as described for the utility piped water, with null hypotheses that there would be not association between thermotolerant coliform presence and the presence of risk factors. The results are shown in Annex 14.

No significant associations were found between risk factors and thermotolerant coliform presence and the null hypotheses were accepted. In a separate analysis in relation to compliance with the Ugandan guideline for untreated supplies of <50cfu/100ml, no factors showed any significant association with failure to comply with the guideline. Given the lack of significant associations between risk factors and exceeding the water quality targets, no logistic regression models were developed.

5.3 Protected point sources

5.3.1 Boreholes

The sampling programme for boreholes was based on a rolling programme of visits with each borehole tested at least twice a year, once in the wet season and once in the dry season. In addition, a study of microbial water quality in boreholes involving monthly sampling over 12 months was undertaken in Mbale, Sototi and Tororo to investigate temporal variations.

The water quality data from all the towns where boreholes were found are summarised in table 5.20 below and shown in more detailed in Annex 15. The table includes the number of samples showing the presence of thermotolerant coliforms and those exceeding 10cfu/100ml, the relaxation suggested by WHO (1993).
Table 5.20: Results of analysis of thermotolerant coliforms in boreholes fitted with handpumps

<table>
<thead>
<tr>
<th>Town</th>
<th>No. samples</th>
<th>No. &gt;0 cfu/100ml</th>
<th>No. ≥10 cfu/100ml</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Median</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entebbe</td>
<td>3</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>8</td>
<td>5</td>
</tr>
<tr>
<td>Mbale</td>
<td>45</td>
<td>40</td>
<td>16</td>
<td>0</td>
<td>TNTC</td>
<td>4.5</td>
</tr>
<tr>
<td>Mbarara</td>
<td>20</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Mukono</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>20</td>
<td>10</td>
</tr>
<tr>
<td>Soroti</td>
<td>168</td>
<td>11</td>
<td>1</td>
<td>0</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>Tororo</td>
<td>48</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>All towns</td>
<td>286</td>
<td>56</td>
<td>18</td>
<td>0</td>
<td>TNTC</td>
<td>0</td>
</tr>
</tbody>
</table>

The quality of water from boreholes in Entebbe, Mbarara, Soroti and Tororo was generally good, with 80.4% of samples providing results of <1 cfu/100ml thermotolerant coliforms and only one sample in each of Mbarara and Tororo exceeded this value. All samples taken from Entebbe, Mbarara and Tororo have less than 10 cfu/100ml thermotolerant coliforms.

In Mbale and Soroti, contamination is more commonly found. In Soroti compliance with the WHO Guideline Value is 93.5% and is 99.4% with the suggested relaxation of 10 cfu/100ml. In Mbale there is only 11.1% compliance with the WHO Guideline Value and 64.4% with the suggested relaxation.

All samples from boreholes from all the towns except Mbale comply with the Uganda guideline for untreated supplies (<50 cfu/100ml), whilst in Mbale a compliance rate of 80% is found. A parallel study performed in Iganga (a small town lying between Jinja and Tororo) tested for faecal streptococci. Out of 138 tests for faecal streptococci, only 5 showed contamination and the maximum number of colonies found was 4 cfu/100ml.

Turbidity was below 5 NTU from all but one sample from Mbale, which showed a
value of 18NTU. Appearance in all cases was clear. The data from the surveillance programme and other studies in Uganda suggest that, with the exception of Mbale, boreholes in the urban areas are capable of providing water of acceptable microbiological quality using current water quality guidelines.

The data for sanitary inspections of boreholes are summarised in table 5.21 below. These data indicate that median sanitary risks are higher than those recorded for the utility and community-managed piped water supplies. There is a marked variation in sanitary risk score within those towns where there were more than a handful of inspections carried out, showing that operation and maintenance performance varied between individual sources as well as between towns.

<table>
<thead>
<tr>
<th>Town</th>
<th>No. inspections</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Median</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entebbe</td>
<td>3</td>
<td>0</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Mbale</td>
<td>45</td>
<td>0</td>
<td>80</td>
<td>30</td>
</tr>
<tr>
<td>Mbarara</td>
<td>10</td>
<td>20</td>
<td>50</td>
<td>30</td>
</tr>
<tr>
<td>Mukono</td>
<td>2</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Soroti</td>
<td>157</td>
<td>10</td>
<td>60</td>
<td>20</td>
</tr>
<tr>
<td>Tororo</td>
<td>33</td>
<td>0</td>
<td>60</td>
<td>30</td>
</tr>
<tr>
<td>Total</td>
<td>253</td>
<td>0</td>
<td>80</td>
<td>20</td>
</tr>
</tbody>
</table>

Table 5.21: Sanitary risk score data for boreholes with handpumps

Following the categorisation system of risk scores suggested by Lloyd and Bartram (1991) the percentage of boreholes categorised as low risk (≤20%) medium risk (30-40%), high risk (60-80%) and very high risk (≥90%) was plotted in figure 5.6 below.

The majority of boreholes fall into the low medium categories. Only in Mbale were significant numbers of boreholes found in the high-risk category. No boreholes fell into the very high-risk category.
Figure 5.6: Proportion of boreholes in sanitary risk categories by town

The frequency of reporting of individual risk factors is shown in table 5.22. Entebbe and Mukono are not reported separately because of the small number of inspections performed. This shows that the frequency of reporting of individual risk factors varied between towns. The difference in frequency of reporting between when thermotolerant coliforms were present and when they were absent is shown in table 5.23. Tororo is not reported separately in table 5.23, as only sample showed the presence of thermotolerant coliforms.
<table>
<thead>
<tr>
<th>Town</th>
<th>Latrine &lt;10m</th>
<th>Latrine uphill</th>
<th>Other pollution uphill</th>
<th>Ponding &lt;2m</th>
<th>Drainage channel faulty</th>
<th>Fence missing/ absent</th>
<th>Apron &lt;1m radius</th>
<th>Spilt water collects on apron</th>
<th>Apron damaged/ cracked</th>
<th>Handpump loose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mbale</td>
<td>51</td>
<td>51</td>
<td>40</td>
<td>36</td>
<td>11</td>
<td>93</td>
<td>0</td>
<td>22</td>
<td>13</td>
<td>4</td>
</tr>
<tr>
<td>Mbarara</td>
<td>0</td>
<td>20</td>
<td>10</td>
<td>40</td>
<td>60</td>
<td>90</td>
<td>10</td>
<td>20</td>
<td>50</td>
<td>0</td>
</tr>
<tr>
<td>Soroti</td>
<td>11</td>
<td>16</td>
<td>13</td>
<td>18</td>
<td>67</td>
<td>94</td>
<td>3</td>
<td>15</td>
<td>19</td>
<td>1</td>
</tr>
<tr>
<td>Tororo</td>
<td>6</td>
<td>0</td>
<td>25</td>
<td>32</td>
<td>50</td>
<td>81</td>
<td>0</td>
<td>39</td>
<td>42</td>
<td>0</td>
</tr>
<tr>
<td>All towns</td>
<td>17</td>
<td>21</td>
<td>20</td>
<td>25</td>
<td>53</td>
<td>91</td>
<td>2</td>
<td>20</td>
<td>22</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 5.22: Percent reporting of individual sanitary risk factors for boreholes

<table>
<thead>
<tr>
<th>Town</th>
<th>Latrine &lt;10m</th>
<th>Latrine uphill</th>
<th>Other pollution uphill</th>
<th>Ponding &lt;2m</th>
<th>Drainage channel faulty</th>
<th>Fence missing/ Absent</th>
<th>Apron &lt;1m radius</th>
<th>Spilt water collects on apron</th>
<th>Apron damaged/ cracked</th>
<th>Handpump loose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mbale</td>
<td>+13</td>
<td>+57</td>
<td>0</td>
<td>+18</td>
<td>-10</td>
<td>+15</td>
<td>0</td>
<td>+3</td>
<td>-7</td>
<td>+5</td>
</tr>
<tr>
<td>Soroti</td>
<td>+3</td>
<td>+5</td>
<td>+1</td>
<td>-3</td>
<td>-3</td>
<td>-1</td>
<td>+4</td>
<td>+15</td>
<td>+10</td>
<td>-1</td>
</tr>
<tr>
<td>All towns</td>
<td>+30</td>
<td>+32</td>
<td>+19</td>
<td>+8</td>
<td>-32</td>
<td>+9</td>
<td>0</td>
<td>+3</td>
<td>+4</td>
<td>+5</td>
</tr>
</tbody>
</table>

Table 5.23: Difference in reporting of sanitary risks for boreholes (all towns, Mbale and Soroti)
5.3.1.1 Relationships between risk factors and microbiological quality

The water quality and sanitary inspection data were analysed to investigate whether there were any relationships between microbiological quality and particular risk factors. The dummy coded variable for presence or absence of thermotolerant coliforms was used in this analysis.

Table 5.23 above provides a summary of the difference in the frequency of reporting of different risk factors between when the target was met and when it was exceeded. Positive figures indicate that frequency of reporting of the risk factor was greater when contamination was found than when it was absent and a negative figure indicates that frequency of reporting was lower when contamination was found than when it was absent. Results are presented on difference in reporting for data from boreholes from all towns, and then separately for boreholes from Mbale and Soroti, as these two towns had most data and more than one contaminated sample.

These data suggest that the location of latrines (both in terms of proximity and whether uphill) and proximity of other sources of pollution (for instance surface water uphill or animal husbandry) are positively associated with contamination events. Although several other factors (ponding of water, fence, apron size, spilt water on the apron and loose handpump) are positively associated with contamination, there is a less marked increase in reporting with contamination events.

In Mbale, the location of a latrine uphill shows the greatest positive association with contamination, with ponding within 2m, a missing/faulty fence and latrine within 10m also showing a marked increase in reporting. Positive associations are also seen with spilt water on the apron and the handpump being loose. In Soroti, the most marked positive associations with contamination are spilt water on the apron and damage to the apron with latrine proximity and location also showing positive associations.

The data for boreholes from all towns were further analysed through a contingency table with odds ratios, with null hypotheses that that there would be no significant association between the presence of a risk factor with the presence of thermotolerant
coliforms. The results of the analyses are summarised in table 5.24 below.

<table>
<thead>
<tr>
<th>Risk factor</th>
<th>Factor present</th>
<th>Thermotolerant coliforms present</th>
<th>Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Latrine within 10m</td>
<td>No</td>
<td>176</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>20</td>
<td>22</td>
</tr>
<tr>
<td>Latrine uphill</td>
<td>No</td>
<td>170</td>
<td>32</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>26</td>
<td>25</td>
</tr>
<tr>
<td>Other pollution uphill</td>
<td>No</td>
<td>166</td>
<td>37</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>30</td>
<td>20</td>
</tr>
<tr>
<td>Drainage allow ponding within 2m</td>
<td>No</td>
<td>149</td>
<td>39</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>47</td>
<td>18</td>
</tr>
<tr>
<td>Drainage channel faulty or needs</td>
<td>No</td>
<td>74</td>
<td>43</td>
</tr>
<tr>
<td>cleaning</td>
<td>Yes</td>
<td>121</td>
<td>14</td>
</tr>
<tr>
<td>Fence missing or absent</td>
<td>No</td>
<td>18</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>177</td>
<td>54</td>
</tr>
<tr>
<td>Apron less than 1m in radius</td>
<td>No</td>
<td>191</td>
<td>57</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Spilt water collects on apron</td>
<td>No</td>
<td>158</td>
<td>44</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>38</td>
<td>13</td>
</tr>
<tr>
<td>Apron damaged or cracked</td>
<td>No</td>
<td>149</td>
<td>48</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>47</td>
<td>9</td>
</tr>
<tr>
<td>Handpump loose at point of attachment</td>
<td>No</td>
<td>195</td>
<td>54</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>1</td>
<td>3</td>
</tr>
</tbody>
</table>

Table 5.24: Contingency table analysis of risk factors and contamination for boreholes

The results indicate that for only three factors is the association between the risk factor and thermotolerant coliform presence significant at the 99% confidence level (latrine within 10m, latrine uphill and other pollution uphill) and for one other (handpump loose) at the 95% level. The null hypotheses are rejected for these factors. The remaining factors do not show significant associations and the null hypotheses were accepted.

A logistic regression model was developed as summarised in table 5.25 below. The null hypothesis was that the logistic regression model would not provide a better fit for the data than an intercept only model. The model contains three factors (latrine within 10m, drainage channel being faulty or requiring cleaning and the handpump being...
loose). The model log estimate value indicates that this is stronger than an intercept only model and the null hypothesis was rejected.

<table>
<thead>
<tr>
<th>Model log estimate</th>
<th>Variables</th>
<th>Variable coefficient</th>
<th>SE</th>
<th>Wald</th>
<th>df</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>219.99</td>
<td>Constant</td>
<td>2.02</td>
<td>1.26</td>
<td>2.57</td>
<td>1</td>
<td>0.109</td>
</tr>
<tr>
<td></td>
<td>Latrine within 10m</td>
<td>-1.56</td>
<td>0.39</td>
<td>16.24</td>
<td>1</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>Drainage channel</td>
<td>1.63</td>
<td>0.37</td>
<td>19.54</td>
<td>1</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>faulty</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Handpump loose at attachment</td>
<td>-3.05</td>
<td>1.25</td>
<td>6.00</td>
<td>1</td>
<td>0.014</td>
</tr>
</tbody>
</table>

Table 5.25: Logistic regression model of risk factors and contamination events for boreholes

The influence of rainfall could not be investigated in depth because of a lack of rainfall data for all the towns. The broad relationship with rainfall was investigated by defining a variable of season. Dates of inspection were classified into wet or dry season using a broad definition of wet seasons being March to May inclusive and September to November inclusive and dry seasons being December to February inclusive and June to August inclusive. No relationships were noted in the presence of contamination with season.

5.3.2 Protected springs

The water quality data for protected springs is summarised in Table 5.26 below and shown in more detail in Annex 16. This indicates that in general water quality is much poorer than from boreholes.
<table>
<thead>
<tr>
<th>Town</th>
<th>No. samples</th>
<th>No. ≥1 cfu/100ml</th>
<th>No. ≥10 cfu/100ml</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Median</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kabale</td>
<td>68</td>
<td>48</td>
<td>19</td>
<td>0</td>
<td>TNTC</td>
<td>3</td>
</tr>
<tr>
<td>Kampala</td>
<td>1155</td>
<td>1009</td>
<td>746</td>
<td>0</td>
<td>TNTC</td>
<td>22</td>
</tr>
<tr>
<td>Masaka</td>
<td>35</td>
<td>28</td>
<td>13</td>
<td>0</td>
<td>TNTC</td>
<td>4</td>
</tr>
<tr>
<td>Mbale</td>
<td>68</td>
<td>63</td>
<td>25</td>
<td>0</td>
<td>TNTC</td>
<td>6.5</td>
</tr>
<tr>
<td>Mbarara</td>
<td>7</td>
<td>7</td>
<td>1</td>
<td>1</td>
<td>23</td>
<td>3</td>
</tr>
<tr>
<td>Mukono</td>
<td>30</td>
<td>28</td>
<td>19</td>
<td>0</td>
<td>TNTC</td>
<td>38</td>
</tr>
<tr>
<td>Soroti</td>
<td>191</td>
<td>158</td>
<td>101</td>
<td>0</td>
<td>TNTC</td>
<td>11</td>
</tr>
<tr>
<td>Tororo</td>
<td>150</td>
<td>91</td>
<td>53</td>
<td>0</td>
<td>TNTC</td>
<td>7.5</td>
</tr>
<tr>
<td>All towns</td>
<td>1666</td>
<td>1432</td>
<td>977</td>
<td>0</td>
<td>TNTC</td>
<td>17</td>
</tr>
</tbody>
</table>

Table 5.26: Results of analysis of thermotolerant coliforms in water from protected springs

Although in most towns samples with less than 1 cfu/100ml were obtained, only a low percentage of samples meet the WHO Guideline value and compliance was particularly low in Kampala and Mukono. When compared against a target of 10 cfu/100ml, many more samples are compliant, although again the percentage compliance is much lower in Kampala and Mukono. When compared against the Ugandan Guideline for untreated supplies, over 50% of samples from all the towns are compliant and in all towns except Kampala and Mukono, over 70% of samples meet the Uganda guideline.

The same categorisation as for boreholes was used in relation to overall risk scores. The sanitary risk scores obtained are summarised below in table 5.27 and figure 5.7.
<table>
<thead>
<tr>
<th>Town</th>
<th>No. inspections</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Median</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kabale</td>
<td>68</td>
<td>0</td>
<td>70</td>
<td>55</td>
</tr>
<tr>
<td>Kampala</td>
<td>1134</td>
<td>0</td>
<td>90</td>
<td>60</td>
</tr>
<tr>
<td>Masaka</td>
<td>33</td>
<td>10</td>
<td>80</td>
<td>60</td>
</tr>
<tr>
<td>Mbale</td>
<td>66</td>
<td>10</td>
<td>80</td>
<td>50</td>
</tr>
<tr>
<td>Mbarara</td>
<td>5</td>
<td>20</td>
<td>70</td>
<td>60</td>
</tr>
<tr>
<td>Mukono</td>
<td>15</td>
<td>30</td>
<td>90</td>
<td>50</td>
</tr>
<tr>
<td>Soroti</td>
<td>168</td>
<td>10</td>
<td>80</td>
<td>50</td>
</tr>
<tr>
<td>Tororo</td>
<td>105</td>
<td>0</td>
<td>80</td>
<td>50</td>
</tr>
<tr>
<td>Total</td>
<td>1594</td>
<td>0</td>
<td>90</td>
<td>50</td>
</tr>
</tbody>
</table>

Table 5.27: Sanitary risk score data for protected springs

The median sanitary risk score for protected springs is high when taking the full data set and when analysing data for each town. These scores are indicative of poor operation and maintenance. When investigating the percent of inspections that would be categorised as low, medium, high or very high risks, the majority of protected are in the medium to high category, with few recorded as low risk. In Kampala and Mukono a small number of inspections fall into the very high-risk category.
Figure 5.7: Percent of inspections of protected spring by risk category

The percent reporting of sanitary risk factors for protected springs is shown in table 5.28 below. These results indicate that overall problems related to the maintenance of the immediate protection works are more significant than potential sources of faecal matter that would contribute to contamination through sub-surface leaching. Of the faecal source factors, other pollution (such as animal husbandry and solid waste) are more commonly reported than pit latrines. There is some variation noted between the different towns in terms of risk reporting, although there is a remarkable consistency for several factors. Of these differences, the most important to note, perhaps, is the higher frequency of reporting of pit latrines uphill and within 30m of springs in Kampala and Mukono and the very low reporting of this factor in Soroti and Tororo.
<table>
<thead>
<tr>
<th>Town</th>
<th>Masonry faulty</th>
<th>Backfill area eroded</th>
<th>Collection area flooded</th>
<th>Fence absent/faulty</th>
<th>Animal access &lt;10m</th>
<th>Latrine uphill within 30m</th>
<th>Surface water collects uphill</th>
<th>Diversion ditch absent/faulty</th>
<th>Other pollution uphill</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kabale</td>
<td>16</td>
<td>41</td>
<td>79</td>
<td>85</td>
<td>78</td>
<td>3</td>
<td>59</td>
<td>81</td>
<td>54</td>
</tr>
<tr>
<td>Kampala</td>
<td>56</td>
<td>46</td>
<td>75</td>
<td>84</td>
<td>84</td>
<td>30</td>
<td>25</td>
<td>79</td>
<td>68</td>
</tr>
<tr>
<td>Masaka</td>
<td>73</td>
<td>67</td>
<td>70</td>
<td>84</td>
<td>94</td>
<td>21</td>
<td>52</td>
<td>91</td>
<td>39</td>
</tr>
<tr>
<td>Mbale</td>
<td>44</td>
<td>21</td>
<td>76</td>
<td>97</td>
<td>91</td>
<td>18</td>
<td>30</td>
<td>62</td>
<td>56</td>
</tr>
<tr>
<td>Mbarara</td>
<td>20</td>
<td>80</td>
<td>40</td>
<td>60</td>
<td>100</td>
<td>20</td>
<td>20</td>
<td>80</td>
<td>40</td>
</tr>
<tr>
<td>Mukono</td>
<td>53</td>
<td>67</td>
<td>93</td>
<td>87</td>
<td>100</td>
<td>47</td>
<td>33</td>
<td>80</td>
<td>7</td>
</tr>
<tr>
<td>Soroti</td>
<td>52</td>
<td>49</td>
<td>75</td>
<td>91</td>
<td>92</td>
<td>1</td>
<td>17</td>
<td>71</td>
<td>43</td>
</tr>
<tr>
<td>Tororo</td>
<td>19</td>
<td>25</td>
<td>61</td>
<td>91</td>
<td>90</td>
<td>0</td>
<td>23</td>
<td>65</td>
<td>50</td>
</tr>
<tr>
<td>Overall</td>
<td>51</td>
<td>45</td>
<td>74</td>
<td>86</td>
<td>85</td>
<td>23</td>
<td>26</td>
<td>77</td>
<td>62</td>
</tr>
</tbody>
</table>

Table 5.28: Percent reporting of individual sanitary risk factors for protected springs
5.3.2.1 Relationships between risk factors and microbiological quality

The sanitary risk and microbiological data from all towns were analysed to assess whether any overall relationship existed between sanitary risk score and the numbers thermotolerant coliforms present. The null hypothesis was that no significant relationship would be found between overall sanitary risk score and number of thermotolerant coliforms present. A Spearman’s rank correlation showed a relationship significant at the 99% (Rs = 0.337, p = 0.01) and the null hypothesis was rejected. The relationship is shown in figure 5.8 below, in which TNTC results are assigned a default value of 1000.

![Figure 5.8: Relationship between sanitary risk score and thermotolerant coliform presence, protected springs](image)

The correlation coefficient is relatively low (although larger than the score obtained for the utility piped water supplies), which suggests that the fit is not very strong. This is supported by the dispersion of data points around the trend line in figure 5.8 above. However, the analysis suggests that the total sanitary inspection score does correlate with the level of thermotolerant coliforms found.

The water quality and sanitary inspection data were analysed to investigate whether there were any relationships between microbiological quality and particular risk factors. The dummy coded variables described in section 3.10 for presence or absence
of thermotolerant coliforms, contamination exceeding 10 cfu/100ml and contamination exceeding 50 cfu/100ml were used in this analysis.

The results of the analysis related to the water quality target of 10 cfu/100ml shown in table 5.29 below. As with the previous analysis of thermotolerant coliform and sanitary inspection data, a positive number indicates that the percentage reporting of the risk factor was higher when contamination was found and a negative number indicates that reporting of the risk factor was lower when contamination was found.
<table>
<thead>
<tr>
<th>Town</th>
<th>Masonry faulty</th>
<th>Backfill area eroded</th>
<th>Collection area flooded</th>
<th>Fence absent/faulty</th>
<th>Animal access &lt;10m</th>
<th>Latrine uphill within 30m</th>
<th>Surface water collects uphill</th>
<th>Diversion ditch absent/faulty</th>
<th>Other pollution uphill</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kabale</td>
<td>+14</td>
<td>+23</td>
<td>+13</td>
<td>+13</td>
<td>+8</td>
<td>-4</td>
<td>+50</td>
<td>+19</td>
<td>+41</td>
</tr>
<tr>
<td>Kampala</td>
<td>+15</td>
<td>+16</td>
<td>+8</td>
<td>+11</td>
<td>+12</td>
<td>+8</td>
<td>+20</td>
<td>+11</td>
<td>+18</td>
</tr>
<tr>
<td>Masaka</td>
<td>+4</td>
<td>0</td>
<td>+21</td>
<td>+10</td>
<td>+11</td>
<td>+45</td>
<td>+24</td>
<td>+2</td>
<td>+17</td>
</tr>
<tr>
<td>Mbale</td>
<td>+7</td>
<td>+11</td>
<td>+8</td>
<td>+5</td>
<td>+8</td>
<td>+22</td>
<td>+14</td>
<td>+9</td>
<td>+26</td>
</tr>
<tr>
<td>Mukono</td>
<td>+34</td>
<td>+28</td>
<td>-11</td>
<td>+6</td>
<td>0</td>
<td>+23</td>
<td>+56</td>
<td>-33</td>
<td>+11</td>
</tr>
<tr>
<td>Soroti</td>
<td>+3</td>
<td>+16</td>
<td>+4</td>
<td>+8</td>
<td>+3</td>
<td>0</td>
<td>+9</td>
<td>+3</td>
<td>+10</td>
</tr>
<tr>
<td>Tororo</td>
<td>+18</td>
<td>+23</td>
<td>0</td>
<td>+1</td>
<td>+1</td>
<td>0</td>
<td>+26</td>
<td>+32</td>
<td>-1</td>
</tr>
<tr>
<td>Overall</td>
<td>+17</td>
<td>+16</td>
<td>+7</td>
<td>+8</td>
<td>+9</td>
<td>+11</td>
<td>+17</td>
<td>+12</td>
<td>+19</td>
</tr>
</tbody>
</table>

Table 5.29: Difference in reporting of sanitary risks for protected springs
The results show that all sanitary risks influence the microbiological quality, thus supporting their inclusion within the inspection form. However, it is clear that different factors have different levels of impact on water quality overall and between different towns. The data suggest that in a number of towns, factors concerning the immediate protection of the spring are most important, whilst in others sources of faeces are more important. Of the faecal sources, surface water collecting uphill and 'other' pollution appear more important than pit latrines, except in Masaka where pit latrines are very influential.

The results of three longitudinal studies are described below to present the relationships between sanitary risk factors and water quality targets. These were:

1. a 13-month study in Kampala of 61 springs undertaken in the early stages of the surveillance project by local environmental health staff;
2. a similar 12-month study in Mbale, Soroti and Tororo undertaken by local environmental health staff; and,
3. a 12-month study of 25 springs in Kampala undertaken in conjunction with the Public Health and Environmental Engineering Laboratory Makerere University, Kampala.

In all cases, analysis of the data used the dummy coded variables described in section 3.10 and that were used in the analysis reported in section 5.3.2.1 above.

5.3.2.2 Case study 1: Kampala longitudinal study

The sites for this study were selected to be representative of the range of results obtained in the initial assessment of protected springs undertaken in 1997/98 and to reflect the range of Parishes (in particular population density). Samples were taken every month from 61 springs over a 13-month period (March 1998 to March 1999 inclusive). The data are shown in Annex 16. The water quality varied significantly over the period for many springs in response to rainfall patterns as shown in figure 5.9. The data were analysed using Spearman's rank correlation to investigate whether there was a significant relationship between rainfall and median levels of thermotolerant coliforms. The null hypothesis was that no significant relationship
would exist between the median number of thermotolerant coliforms and amount of rainfall. The analysis gave a correlation significant at the 95% level (Rs = 0.561, p = 0.046) and the null hypothesis was rejected.

Figure 5.9: Relationship between median contamination and monthly rainfall, case study 1

The data were analysed using Spearman’s rank correlation statistic to see whether there was a relationship between sanitary risk score and contamination. The hypothesis was that a significant positive relationship would be found and the null hypothesis was that no significant relationship would be found. The analysis showed a significant correlation between contamination found and overall sanitary risk score and thus the null hypothesis was rejected (Rs = 0.36, p = 0.01).

The Parishes in which springs were found were categorised into high, medium and low density using the methodology outlined in section 3.11. Table 5.30 shows that median contamination was higher in high density Parishes compared to low-medium density Parishes and sanitary risks were slightly lower in low-density Parishes compared to high and medium density Parishes.
<table>
<thead>
<tr>
<th>Density</th>
<th>No. samples &amp; inspections</th>
<th>Median cfu/100ml</th>
<th>Median sanitary risk (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>266</td>
<td>27</td>
<td>60</td>
</tr>
<tr>
<td>Medium</td>
<td>147</td>
<td>10</td>
<td>60</td>
</tr>
<tr>
<td>Low</td>
<td>196</td>
<td>7.5</td>
<td>50</td>
</tr>
</tbody>
</table>

Table 5.30: Median microbiological quality and sanitary risk by population category

The data were analysed using the Kruskal-Wallis test to see if there was a difference in median contamination between the different categories of population density. The null hypothesis was that no significant difference would be found in median contamination between the different categories of population density. The result was significant above the 99% confidence level ($\chi^2 = 60.16, df = 2, p < 0.001$) and the null hypothesis was rejected. As the median contamination of the medium-density and low-density springs appeared to be similar, a $\chi^2$ test was performed to see whether there was a significant difference between the two. The null hypothesis was that no significant difference would be found in median contamination between the two groups. The result showed no significant difference ($\chi^2 = 1.95, df = 1, p = 0.162$) and the null hypothesis was accepted. The Parish density variable was therefore transformed into a dummy coded binomial categorical variable of high or low-medium density for subsequent analyses.

Rainfall data from the Makerere University weather station were collected from the Meteorological Office in Kampala. The data were transformed into three dummy binary variables as follows:

1. rainfall recorded on the day of sampling (No = 0, Yes = 1);
2. rainfall recorded on the day of sampling or the previous day (No = 0, Yes = 1);
   and,
3. rainfall recorded on the day of sampling or the previous 4 days (No = 0, Yes = 1).

The relationship between these variables, individual risk factors, rainfall events and population density were analysed using odds ratios in contingency tables. The
analysis for the dummy variable of the presence of more than 10cfu/100ml is presented in table 5.3, with the results for other two targets shown in Annex 16. The null hypotheses were that no significant association would be seen between the presence of a risk factor and the presence of thermotolerant coliforms at 10cfu/100ml or above.

The contingency table indicates that exceeding the water quality target of below 10cfu/100ml, all the sanitary risk factors show significant associations, with all but flooding of the collection area being significant at the 99% confidence level. Population density also shows an association significant above the 99% confidence level. The null hypotheses were therefore rejected for all these factors. No significant associations are noted for the rainfall variables.

For exceeding the water quality target of absence of thermotolerant coliforms, only animal access is not significant to at least the 95% confidence level and faulty diversion ditch significant only at the 95% confidence level, the remaining factors being significant at the 99% confidence level. The null hypotheses were therefore rejected for all factors except animal access. Population density is significant at the 95% level and again the null hypothesis was rejected. No significant association is seen with rainfall variables and the null hypotheses were accepted.

For exceeding the target of below 50cfu/100ml, flooding of the collection area shows no significant association. All other risk factors except faulty masonry and eroded backfill are significant at the 99% confidence level. Population density has an association significant at the 99% confidence level. For all these factors except flooding of the collection area, the null hypotheses were rejected.

The analysis shows that the inclusion of all the risk factors is generally supported given their association with contamination and that population density is also an important factor in the presence of thermotolerant coliforms. The limited relationships to rainfall are surprising and are contrary to the field experience and to the other case studies noted below.
<table>
<thead>
<tr>
<th>Risk factors</th>
<th>≥10cfu/100ml</th>
<th></th>
<th>&gt;1cfu/100ml</th>
<th></th>
<th>≥50cfu/100ml</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No</td>
<td>Yes</td>
<td>P</td>
<td>OR 95% CI</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Faulty masonry</td>
<td>158</td>
<td>115</td>
<td>&lt;0.001</td>
<td>2.23 1.61-3.09</td>
<td>71</td>
<td>215</td>
</tr>
<tr>
<td>Backfill area eroded</td>
<td>180</td>
<td>103</td>
<td>0.003</td>
<td>1.63 1.18-2.26</td>
<td>76</td>
<td>263</td>
</tr>
<tr>
<td>Collection area floods</td>
<td>82</td>
<td>191</td>
<td>0.047</td>
<td>1.44 1.01-2.08</td>
<td>41</td>
<td>118</td>
</tr>
<tr>
<td>Fence absent or faulty</td>
<td>74</td>
<td>199</td>
<td>&lt;0.001</td>
<td>2.13 1.42-3.18</td>
<td>33</td>
<td>91</td>
</tr>
<tr>
<td>Animal access &lt;10m</td>
<td>65</td>
<td>208</td>
<td>0.003</td>
<td>1.88 1.24-2.84</td>
<td>28</td>
<td>85</td>
</tr>
<tr>
<td>Latrine &lt;30m uphill of spring</td>
<td>226</td>
<td>232</td>
<td>&lt;0.001</td>
<td>2.16 1.46-3.18</td>
<td>99</td>
<td>359</td>
</tr>
<tr>
<td>Surface water uphill</td>
<td>237</td>
<td>218</td>
<td>&lt;0.001</td>
<td>3.56 2.35-5.40</td>
<td>100</td>
<td>355</td>
</tr>
<tr>
<td>Diversion ditch faulty</td>
<td>81</td>
<td>192</td>
<td>0.002</td>
<td>1.83 1.25-2.67</td>
<td>36</td>
<td>108</td>
</tr>
<tr>
<td>Other pollution uphill</td>
<td>131</td>
<td>142</td>
<td>&lt;0.001</td>
<td>3.05 2.16-4.32</td>
<td>66</td>
<td>143</td>
</tr>
<tr>
<td>High population density</td>
<td>186</td>
<td>157</td>
<td>&lt;0.001</td>
<td>2.44 1.75-3.40</td>
<td>75</td>
<td>268</td>
</tr>
<tr>
<td>Rainfall within previous 5 days</td>
<td>61</td>
<td>212</td>
<td>0.469</td>
<td>1.15 0.78-1.71</td>
<td>30</td>
<td>98</td>
</tr>
<tr>
<td>Rainfall within previous 2 days</td>
<td>129</td>
<td>150</td>
<td>0.520</td>
<td>1.11 0.81-1.53</td>
<td>57</td>
<td>222</td>
</tr>
<tr>
<td>Rainfall with previous 1 day</td>
<td>182</td>
<td>218</td>
<td>0.644</td>
<td>1.08 0.77-1.52</td>
<td>78</td>
<td>322</td>
</tr>
</tbody>
</table>

Table 5.31: Contingency table for risk factors in relation to dummy variables for microbiological quality from Kampala case study 1
Logistic regression models for the three water quality targets were developed for all the data and are shown in table 5.32 below. The null hypotheses were that these models would provide a better fit than an intercept only model. The models show that sources of faecal material are the main factors of importance and the protection works factors are of more limited importance, although protection works factors (notably faulty masonry) are included. Rainfall is included only in the model for exceeding the below 1 cfu/100ml target. Population density is included for both the other models.

<table>
<thead>
<tr>
<th>Model</th>
<th>Model log estimate</th>
<th>Variables in model</th>
<th>Variable coefficient</th>
<th>SE</th>
<th>Wald</th>
<th>df</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>All data ≥10 cfu/100ml</td>
<td>726.03</td>
<td>Constant</td>
<td>2.51</td>
<td>0.30</td>
<td>70.32</td>
<td>1</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Masonry faulty</td>
<td>-0.63</td>
<td>0.19</td>
<td>11.01</td>
<td>1</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fence faulty</td>
<td>-0.55</td>
<td>0.23</td>
<td>5.91</td>
<td>1</td>
<td>0.015</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Latrine within 30m</td>
<td>-0.68</td>
<td>0.22</td>
<td>5.32</td>
<td>1</td>
<td>0.002</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Surface water uphill</td>
<td>-0.91</td>
<td>0.23</td>
<td>16.19</td>
<td>1</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Other pollution uphill</td>
<td>-0.68</td>
<td>0.2</td>
<td>12.08</td>
<td>1</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High density</td>
<td>-0.72</td>
<td>0.19</td>
<td>14.23</td>
<td>1</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>All data &gt;0 cfu/100ml</td>
<td>512.20</td>
<td>Constant</td>
<td>3.83</td>
<td>0.43</td>
<td>76.61</td>
<td>1</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Masonry faulty</td>
<td>-0.65</td>
<td>0.23</td>
<td>7.65</td>
<td>1</td>
<td>0.006</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Collection area flooded</td>
<td>-0.40</td>
<td>0.24</td>
<td>2.78</td>
<td>1</td>
<td>0.096</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Latrine within 30m</td>
<td>-0.88</td>
<td>0.33</td>
<td>7.11</td>
<td>1</td>
<td>0.008</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Surface water uphill</td>
<td>-0.72</td>
<td>0.34</td>
<td>4.53</td>
<td>1</td>
<td>0.033</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Other pollution uphill</td>
<td>-1.06</td>
<td>0.23</td>
<td>21.30</td>
<td>1</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rainfall &lt;5 days</td>
<td>0.52</td>
<td>0.26</td>
<td>3.96</td>
<td>1</td>
<td>0.047</td>
</tr>
<tr>
<td>All data ≥50 cfu/100ml</td>
<td>537.14</td>
<td>Constant</td>
<td>0.45</td>
<td>0.25</td>
<td>3.13</td>
<td>1</td>
<td>0.077</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fence faulty</td>
<td>-1.06</td>
<td>0.34</td>
<td>10.09</td>
<td>1</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Latrine within 30m</td>
<td>-0.55</td>
<td>0.23</td>
<td>5.56</td>
<td>1</td>
<td>0.018</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Surface water uphill</td>
<td>-0.51</td>
<td>0.23</td>
<td>4.76</td>
<td>1</td>
<td>0.029</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Other pollution uphill</td>
<td>-0.69</td>
<td>0.29</td>
<td>5.73</td>
<td>1</td>
<td>0.017</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High density</td>
<td>-1.40</td>
<td>0.23</td>
<td>35.87</td>
<td>1</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>
Table 5.32: Logistic regression models for contamination and risk factors for Kampala case study 1

Models were developed independently for exceeding the water quality target of <10 cfu/100ml for low-medium areas and high-density areas and are also shown in table 5.32 and these show differences to the model for all data. In the high-density areas pathway factors are of greater importance and latrines are not included in the final model. The low-medium density area model shows faecal sources predominating, with flooding of the collection area and faulty masonry also being included.

The analysis from this study suggests that rainfall has limited influence on the presence of thermotolerant coliforms and places greater emphasis on sources of faecal material where sub-surface leaching would be expected to cause contamination. This is somewhat different from the contingency tables and the simple frequency plots for the different water quality targets, where pathway factors reflecting direct ingress are more important.

A pilot project to re-protect springs in high-density areas, which included
improvements in the completion measures, showed 2-log reductions in thermotolerant coliform levels, despite the presence of latrines within 30m uphill. This suggests that latrine presence within 30m was not as important as suggested by the logistic regression models. One problem may be that not every spring was visited every month and within each month the sampling of the springs occurred on different days. This may have led to some bias in the results.

5.3.2.3 Case study 2: Protected springs in Eastern Towns (Mbale, Soroti and Tororo).

A total of 24 springs were sampled every month from towns located in the east of Uganda. Four springs were selected in Mbale, twelve in Soroti and eight in Tororo. The data were analysed using the Spearman's rank correlation statistic to see whether there was a correlation between contamination and sanitary risk score, with the null hypothesis that no significant relationship would be found between sanitary risk score and numbers of thermotolerant coliforms present. Results of TNTC were allocated a default value of 500 cfu/100ml. The analysis produced a significant correlation between sanitary risk score and numbers of thermotolerant coliforms present (Rs = 0.22, p =0.01) and the null hypothesis was rejected. The relationship was not strong as shown by the dispersion of the data around the trend line shown in figure 5.10 below. The data could not be analysed in relation to rainfall, as no data were available for the individual towns.
Figure 5.10: Relationship between sanitary risk and numbers of thermotolerant coliforms, springs from Eastern towns

The data were analysed to test the relationships with individual risk factors. The null hypotheses were that no significant association would be found between the presence of a risk factor and exceeding of the water quality targets. The contingency table for analysis of the data is shown below in table 5.33.

For the analysis of exceeding the <10 cfu/100ml target only two factors (erosion of the backfill area and diversion ditch faulty) show associations significant at the 99% confidence level and two further factors (fence faulty/absent and surface water collecting uphill) are significant at the 95% level. For these four factors the null hypotheses were rejected. The other factors did not show a significant association with exceeding the target and the null hypotheses were accepted.

For the analysis of exceeding the <1 cfu/100ml target, only the factor fence faulty/absent showed an association significant at the 99% confidence level and eroded backfill shows an association significant at the 95% confidence level. For these two factors the null hypotheses were rejected. The other factors do not show a significant association and the null hypotheses were accepted.

For the analysis of exceeding the <50 cfu/100ml target, only surface water uphill
show a significant association with exceeding the target and the null hypothesis was rejected for this factor, but accepted for all other factors. These analyses suggest that problems related to source protection works are more important than sources of faecal material when the water quality targets is exceeded.
<table>
<thead>
<tr>
<th>Risk factors</th>
<th>≥10cfu/100ml</th>
<th></th>
<th>&gt;1cfu/100ml</th>
<th></th>
<th>≥50cfu/100ml</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No</td>
<td>Yes</td>
<td>p</td>
<td>Odds ratio</td>
<td>95% CI</td>
<td>No</td>
</tr>
<tr>
<td>Faulty masonry</td>
<td>No</td>
<td>Yes</td>
<td>103</td>
<td>58</td>
<td>0.278</td>
<td>1.29</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td></td>
<td>81</td>
<td>59</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Backfill area eroded</td>
<td>No</td>
<td>Yes</td>
<td>117</td>
<td>44</td>
<td>&lt;0.001</td>
<td>2.51</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td></td>
<td>72</td>
<td>68</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Collection area floods</td>
<td>No</td>
<td>Yes</td>
<td>45</td>
<td>116</td>
<td>0.905</td>
<td>0.97</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td></td>
<td>40</td>
<td>100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fence absent or faulty</td>
<td>No</td>
<td>Yes</td>
<td>16</td>
<td>145</td>
<td>0.039</td>
<td>2.96</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td></td>
<td>5</td>
<td>134</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Animal access &lt;10m</td>
<td>No</td>
<td>Yes</td>
<td>13</td>
<td>148</td>
<td>0.184</td>
<td>1.96</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td></td>
<td>6</td>
<td>134</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Latrine &lt;30m uphill of spring</td>
<td>No</td>
<td>Yes</td>
<td>157</td>
<td>4</td>
<td>0.583</td>
<td>1.45</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td></td>
<td>135</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surface water uphill</td>
<td>No</td>
<td>Yes</td>
<td>136</td>
<td>25</td>
<td>0.030</td>
<td>1.88</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td></td>
<td>104</td>
<td>36</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diversion ditch faulty</td>
<td>No</td>
<td>Yes</td>
<td>64</td>
<td>97</td>
<td>0.003</td>
<td>2.14</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td></td>
<td>33</td>
<td>107</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other pollution uphill</td>
<td>No</td>
<td>Yes</td>
<td>90</td>
<td>71</td>
<td>0.078</td>
<td>1.51</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td></td>
<td>64</td>
<td>76</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 5.33: Contingency table for risk factors in relation to dummy variables for microbiological quality from Eastern Towns case study
A logistic regression model was developed for the exceeding <10 cfu/100 ml, which is shown in table 5.34 below.

<table>
<thead>
<tr>
<th>Model log estimate</th>
<th>Variables in model</th>
<th>Variable coefficient</th>
<th>SE</th>
<th>Wald</th>
<th>df</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>392.57</td>
<td>Constant</td>
<td>0.63</td>
<td>0.21</td>
<td>8.84</td>
<td>1</td>
<td>0.003</td>
</tr>
<tr>
<td></td>
<td>Backfill area</td>
<td>-0.88</td>
<td>0.25</td>
<td>12.55</td>
<td>1</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>eroded</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Diversion ditch</td>
<td>0.72</td>
<td>0.26</td>
<td>7.49</td>
<td>1</td>
<td>0.006</td>
</tr>
<tr>
<td></td>
<td>missing/faulty</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 5.34: Logistic regressions for contamination and risk factors for Eastern Towns study

The final model only includes three factors, all of which relate to the immediate protection works of the spring, suggesting that these exert the principal influence on contamination. Models were not developed for exceeding the other targets because there were a very limited number of factors showing any significant association in the contingency table analyses.

5.3.2.4 Case study 3: Assessing the risk to groundwater from on-site sanitation (ARGOSS)

In this case study, 25 springs were selected from the springs identified during the inventory. The study had two objectives:

1. to assess whether on-site sanitation was an important cause of groundwater contamination and what distance was required to minimise any influence; and,
2. to assess whether other factors were more important in causing contamination.

Selected springs were classified as being in high and low-density areas, which was defined qualitatively based on the area immediately surrounding the spring up to a distance of about 100 m. Samples were taken every month and analysed for thermotolerant coliforms and faecal streptococci at the Makerere University Public Health and Environmental Engineering laboratory. The full findings of this study are reported in Howard et al. (2002b).
Figure 5.11: Variation in median numbers of indicator bacteria and rainfall, case study 3.

The data was analysed to investigate the relationship with rainfall using the Spearman’s rank correlation statistic. Analysis was performed to see whether median contamination varied with the monthly rainfall amount and the amount of rainfall the 24, 48 and 120 hours prior to sampling. The null hypotheses were that no significant correlations would be found between median contamination and rainfall. The results of this analysis are shown in table 5.35 below.

<table>
<thead>
<tr>
<th>Rainfall period</th>
<th>Thermotolerant coliforms</th>
<th>Faecal streptococci</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rs</td>
<td>p</td>
</tr>
<tr>
<td>Monthly rainfall</td>
<td>0.62</td>
<td>0.05</td>
</tr>
<tr>
<td>Rainfall in previous 24 hours</td>
<td>0.92</td>
<td>0.01</td>
</tr>
<tr>
<td>Rainfall in previous 48 hours</td>
<td>0.79</td>
<td>0.01</td>
</tr>
<tr>
<td>Rainfall in previous 120 hours</td>
<td>0.51</td>
<td>0.05</td>
</tr>
</tbody>
</table>

Table 5.35: Results of correlation analysis between rainfall and median microbiological results
The data show that all levels of rainfall show significant correlations with median numbers of thermotolerant coliforms and the null hypotheses were rejected. Significant correlations are seen between median faecal streptococci numbers and rainfall within 24 and 48 hours and the null hypotheses were rejected. No significant correlations are seen with median faecal streptococci numbers and monthly or 120 hour rainfall and for these correlations the null hypotheses are accepted.

Hazard assessments were undertaken to determine the number of latrines and solid waste found within 10m, 20m 30m and 50m of the springs. In addition, sanitary inspections of source completion measures was also undertaken. The forms used are shown in Annex 4.

The data were analysed to see whether a relationship existed between sanitary risk score and numbers of indicator bacteria found, with a null hypothesis that no significant relationship would be found. When using the data from all the springs there is a strong correlation between median risk and median thermotolerant coliforms ($R_s = 0.529$, $p < 0.01$). The same is true for faecal streptococci ($R_s = 0.582$, $p < 0.01$). In both cases the null hypotheses were rejected. However, when the data from high density and low-density areas were analysed separately, no significant relationship was noted with median risk.

In addition to the dummy codes variables defined for thermotolerant coliform in section 3.10, the faecal streptococci data were transformed into dummy coded variables in SPPS, presence/absence of faecal streptococci and contamination exceeding 10 cfu/100ml. These two levels of contamination were selected on the basis of the results obtained. The coding was the same as for the thermotolerant coliform data.

The data were analysed in contingency tables. The data for variables <1cfu/100ml faecal streptococci and 10cfu/100ml thermotolerant coliforms are discussed here and shown in table 5.36, with the remaining models shown in Annex 16.
<table>
<thead>
<tr>
<th>Variable</th>
<th>FS 1cfu/100ml</th>
<th></th>
<th>TTC 10cfu/100ml</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Factor</td>
<td>No</td>
<td>Yes</td>
<td>p-value</td>
</tr>
<tr>
<td>Faulty masonry</td>
<td>No</td>
<td>65</td>
<td>40</td>
<td>0.008</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>96</td>
<td>113</td>
<td></td>
</tr>
<tr>
<td>Backfill area eroded</td>
<td>No</td>
<td>74</td>
<td>31</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>107</td>
<td>102</td>
<td></td>
</tr>
<tr>
<td>Collection area floods</td>
<td>No</td>
<td>68</td>
<td>37</td>
<td>0.890</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>137</td>
<td>72</td>
<td></td>
</tr>
<tr>
<td>Fence absent or faulty</td>
<td>No</td>
<td>5</td>
<td>100</td>
<td>0.052</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>2</td>
<td>207</td>
<td></td>
</tr>
<tr>
<td>Animal access &lt;10m</td>
<td>No</td>
<td>2</td>
<td>103</td>
<td>0.488</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>2</td>
<td>207</td>
<td></td>
</tr>
<tr>
<td>Surface water uphill</td>
<td>No</td>
<td>87</td>
<td>18</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>119</td>
<td>90</td>
<td></td>
</tr>
<tr>
<td>Diversion ditch faulty</td>
<td>No</td>
<td>32</td>
<td>73</td>
<td>0.679</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>59</td>
<td>150</td>
<td></td>
</tr>
<tr>
<td>Other pollution uphill</td>
<td>No</td>
<td>5</td>
<td>100</td>
<td>0.259</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>5</td>
<td>204</td>
<td></td>
</tr>
<tr>
<td>Latrine &lt;30m uphill of spring</td>
<td>No</td>
<td>80</td>
<td>25</td>
<td>0.455</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>151</td>
<td>58</td>
<td></td>
</tr>
<tr>
<td>Latrine &lt;50m uphill of spring</td>
<td>No</td>
<td>39</td>
<td>66</td>
<td>0.547</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>85</td>
<td>124</td>
<td></td>
</tr>
<tr>
<td>High population density</td>
<td>No</td>
<td>60</td>
<td>45</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>66</td>
<td>143</td>
<td></td>
</tr>
<tr>
<td>Waste &lt;10m uphill of spring</td>
<td>No</td>
<td>73</td>
<td>32</td>
<td>0.150</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>128</td>
<td>81</td>
<td></td>
</tr>
<tr>
<td>Waste &lt;20m uphill of spring</td>
<td>No</td>
<td>45</td>
<td>60</td>
<td>0.231</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>75</td>
<td>134</td>
<td></td>
</tr>
<tr>
<td>Waste &lt;30m uphill of spring</td>
<td>No</td>
<td>17</td>
<td>88</td>
<td>0.590</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>39</td>
<td>170</td>
<td></td>
</tr>
<tr>
<td>Rainfall within previous 5 days</td>
<td>No</td>
<td>24</td>
<td>81</td>
<td>0.009</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>24</td>
<td>185</td>
<td></td>
</tr>
<tr>
<td>Rainfall within previous 2 days</td>
<td>No</td>
<td>67</td>
<td>38</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>73</td>
<td>136</td>
<td></td>
</tr>
<tr>
<td>Rainfall with previous 1 day</td>
<td>No</td>
<td>85</td>
<td>20</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>130</td>
<td>79</td>
<td></td>
</tr>
</tbody>
</table>

Table 5.36: Contingency table for analysis of sanitary risk factors and microbial quality from ARGOSS case study

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Only three risk factors were significant at the 99% level for the presence of faecal streptococci (eroded backfill area, surface water uphill and faulty masonry) and one other (absence of a fence) being significant to the 95% level. The association between faecal streptococci and population density and faecal streptococci and rainfall within 24, 48 and 120 hour periods were all significant at the 99% level.

For 10 cfu/100ml thermotolerant coliforms, four sanitary risk or hazard factors (erosion of the backfill area, surface water uphill, waste within 10m and waste within 20m) are significant at a 99% level. The association with high population density and rainfall within the previous 24, 48 and 120 hour periods are also significant at the 99% level. Flooding of the collection area, other pollution uphill, waste within 30m and latrines within 30m all have odds ratios significant at the 95% level.

Logistic regression models were developed including all co-variates where odds ratios showed relationships significant at least to the 95% level. Only the most significant rainfall variable was included and where two variables both had the same significance, the variable with the largest odds ratio score was included. Although not significant at least to the 95% level, latrine proximity within 30m was forced into the model as this was still deemed to be a plausible route of contamination. The results are shown in table 5.37 below.
### Logistic regressions for protected springs Kampala case study 2

<table>
<thead>
<tr>
<th>Model</th>
<th>Model log estimate</th>
<th>Variables in model</th>
<th>Variable coefficient</th>
<th>SE</th>
<th>Wald</th>
<th>df</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Faecal streptococci &gt;0cfu/100ml</td>
<td>343.27</td>
<td>Constant</td>
<td>2.63</td>
<td>0.36</td>
<td>54.28</td>
<td>1</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Eroded</td>
<td>-0.8</td>
<td>0.29</td>
<td>7.70</td>
<td>1</td>
<td>0.006</td>
</tr>
<tr>
<td></td>
<td></td>
<td>backfill</td>
<td>-1.94</td>
<td>0.88</td>
<td>4.90</td>
<td>1</td>
<td>0.027</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Faulty fence</td>
<td>-1.07</td>
<td>0.32</td>
<td>11.19</td>
<td>1</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Surface water uphill</td>
<td>-1.34</td>
<td>0.27</td>
<td>23.92</td>
<td>1</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rainfall ≤2days</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thermotolerant coliforms ≥10cfu/100ml</td>
<td>338.11</td>
<td>Constant</td>
<td>2.06</td>
<td>0.37</td>
<td>30.8</td>
<td>1</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Eroded</td>
<td>-0.72</td>
<td>0.34</td>
<td>4.50</td>
<td>1</td>
<td>0.034</td>
</tr>
<tr>
<td></td>
<td></td>
<td>backfill</td>
<td>0.57</td>
<td>0.29</td>
<td>3.93</td>
<td>1</td>
<td>0.047</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Collection area flooded</td>
<td></td>
<td>0.7</td>
<td>3.2</td>
<td>1</td>
<td>0.031</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Surface water uphill</td>
<td>-0.7</td>
<td>0.32</td>
<td>4.67</td>
<td>1</td>
<td>0.031</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High density</td>
<td>-1.02</td>
<td>0.35</td>
<td>8.73</td>
<td>1</td>
<td>0.003</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rainfall ≤2days</td>
<td>-1.64</td>
<td>0.29</td>
<td>32.97</td>
<td>1</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

**Table 5.37: Logistic regressions for protected springs Kampala case study 2**

Isolation of faecal streptococci colonies appears to be primarily related to the erosion of the backfill area, lack of fence, surface water uphill and rainfall occurring within the previous 48 hours. The model for thermotolerant coliforms incorporates 5 factors, including erosion of the backfill area, surface water uphill, flooding of the collection area, rainfall within 48 hours, and population density.

### 5.4 Household water

Samples were taken from water stored in households in all towns as part of the monitoring programmes. A total of ten samples per month were taken in each Division, with different households being selected each month. The results from household tests are summarised in Table 5.38 below and the data shown in Annex 17.

The results for median numbers of thermotolerant coliforms show that contamination of household water was generally low. This is true in particular for Kampala, where the median number of thermotolerant coliforms was below 1cfu/100ml and 51.1% of
samples showed <1 cfu/100ml. In all towns, the range of results shows some households with extremely high levels of thermotolerant coliforms.

<table>
<thead>
<tr>
<th>Town</th>
<th>No. samples</th>
<th>No. samples &lt;1 cfu/100ml</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Median</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entebbe</td>
<td>51</td>
<td>19</td>
<td>0</td>
<td>TNTC</td>
<td>4</td>
</tr>
<tr>
<td>Jinja</td>
<td>58</td>
<td>16</td>
<td>0</td>
<td>TNTC</td>
<td>4</td>
</tr>
<tr>
<td>Kabale</td>
<td>62</td>
<td>16</td>
<td>0</td>
<td>TNTC</td>
<td>4</td>
</tr>
<tr>
<td>Kampala</td>
<td>648</td>
<td>331</td>
<td>0</td>
<td>TNTC</td>
<td>0</td>
</tr>
<tr>
<td>Masaka</td>
<td>47</td>
<td>11</td>
<td>0</td>
<td>TNTC</td>
<td>6</td>
</tr>
<tr>
<td>Mbale</td>
<td>82</td>
<td>19</td>
<td>0</td>
<td>TNTC</td>
<td>2</td>
</tr>
<tr>
<td>Mbarara</td>
<td>65</td>
<td>21</td>
<td>0</td>
<td>TNTC</td>
<td>2</td>
</tr>
<tr>
<td>Mukono</td>
<td>6</td>
<td>0</td>
<td>1</td>
<td>180</td>
<td>27.5</td>
</tr>
<tr>
<td>Soroti</td>
<td>212</td>
<td>13</td>
<td>0</td>
<td>TNTC</td>
<td>19</td>
</tr>
<tr>
<td>Tororo</td>
<td>91</td>
<td>30</td>
<td>0</td>
<td>TNTC</td>
<td>13</td>
</tr>
<tr>
<td>All towns</td>
<td>1322</td>
<td>476</td>
<td>0</td>
<td>TNTC</td>
<td>4</td>
</tr>
</tbody>
</table>

Table 5.38: Summary of analyses of thermotolerant coliforms in household water

In the water usage studies in Kampala and Soroti, households were asked whether they ever treated their water. The data are shown in Annex 18. In Kampala, 953 households (92.1%) stated that they boiled their water and in Soroti 42 (30%) stated the same. The results of the household water testing in Kampala do not provide evidence that boiling is practised by such a large proportion of households, or if they do there is considerable post-boiling recontamination. The findings from Soroti are similar, as the proportion of household water quality tests showing an absence of thermotolerant coliforms (6.1%) was much lower than the proportion of households stating that they boiled water before drinking.

It was considered likely that the quality of water stored in households would have improved over time because the surveillance staff incorporated the water quality data in hygiene education programmes. It was also considered that the implementation of the surveillance visits and reporting of the data to communities would have had a beneficial impact on household water quality. The variation in household water
quality over the period of study is shown for Kampala, Mbale, Soroti and Tororo in figure 5.11 below. Only data from these towns are shown as these were the towns where testing was carried out over the longest period of time.

![Figure 5.12: Median thermotolerant coliforms in household water for Kampala, Mbale, Soroti and Tororo by quarter and year](image)

This graph shows that in Soroti a significant reduction in median thermotolerant coliform numbers after the initiation of surveillance activities, but then remained at a relatively high level before reducing in the final quarter of 1999. This suggests that there was overall limited impact on household water quality in the surveillance programme, apart from the initial gains. However, the usual means of storing water in Soroti was in clay pots and therefore the possibility of the thermotolerant coliforms being derived from biofilm cannot be excluded.

The median number of thermotolerant coliforms remained relatively low in Mbale, although the final quarter showed higher levels of contamination in a few households. However, the quality did not appreciably change over this period, suggesting that the good water quality may have been strongly related to the source of water rather than by any educational work undertaken by surveillance staff. The quality of water varied significantly between quarters in Tororo, but showed little overall improvement.

In Kampala, median levels of contamination were always relatively low, but did decrease during implementation of the surveillance activities suggesting that the
surveillance staff were having an impact on household water handling practices.

There were notable differences between Divisions in the City as shown in table 5.39 below. In this table data for 1998 are aggregated as some Divisions undertook testing in the 3rd quarter and some in the 4th quarter.

<table>
<thead>
<tr>
<th>Division</th>
<th>Quarter and year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central</td>
<td>0</td>
</tr>
<tr>
<td>Kawempe</td>
<td>9</td>
</tr>
<tr>
<td>Makindye</td>
<td>24</td>
</tr>
<tr>
<td>Nakawa</td>
<td>0</td>
</tr>
<tr>
<td>Rubaga</td>
<td>50</td>
</tr>
</tbody>
</table>

Table 5.39: Median thermotolerant coliforms from household water tests in Kampala by Division and quarter

Central and Rubaga Divisions showed low levels of contamination (both in terms of median values and range) throughout 1999, with Kawempe Division also showing definite improvement. Makindye Division performance was more variable and in Nakawa Division water quality improvements were less significant. This suggests that the use of the data by staff varied across the City, but showed effective improvements in some communities.

It could be considered likely that the quality of water stored in the home would be influenced by the quality of the source water, with households collecting water from more contaminated sources (particularly protected springs) being more likely to have contamination in the household water. It proved difficult to undertake a systematic analysis of these data, as most samples from the households could not be paired with the source of water used. This was because in many cases field staff found it difficult to collect this information because the household was uncertain.

From the total of 1322 samples taken, 171 could be paired against a source. Over 60% of these are drawn from Jinja (where the absence of any other protected source type meant that it could be assumed that taps were used by all families) and from a pilot
study in Soroti. Samples were also included from Entebbe (13), Kampala (19), Kabale (10), Masaka (2), Mbale (20) and Tororo (2). The sources noted included 10 samples where the source was rainwater.

Initial assessment of the data suggested that where the source of water came from an NW&SC supply or rainwater, contamination was less commonly found than from other sources. A dummy binary variable was defined in SPSS to differentiate NW&SC and rainwater from water from other sources (NW&SC & rainwater = 1, other sources = 0). The data were analysed using $\chi^2$ with the null hypothesis was that no significant difference would be seen in the number of samples showing the presence of thermotolerant coliforms between the two dummy variables. The results of the analysis showed that 'other sources' had a higher number of samples showing the presence of thermotolerant coliforms, significant at the 99% confidence level ($\chi^2 = 20.88, p<0.001, df = 1$) and the null hypothesis was rejected.
Chapter Six

Results for other indicators of water supply from field studies

6.1 Introduction
This chapter presents the data collected and statistical analysis on availability of water sources (6.2), use of water sources by low-income households (6.3), cost of water (6.4), continuity of supply (6.5), estimates of leakage (6.6) and quantities of water used (6.7).

6.2 Availability and access to water supplies

6.2.1 Inventory data
The numbers of water sources from the inventories undertaken are shown in table 6.1 below. The data presented are the total number of water sources by category (piped, protected point source and unprotected sources). Figure 6.1 shows the proportion of each category of source in each study town.
<table>
<thead>
<tr>
<th>Town</th>
<th>Taps</th>
<th>Protected sources</th>
<th>Unprotected sources</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entebbe</td>
<td>23</td>
<td>15</td>
<td>6</td>
<td>44</td>
</tr>
<tr>
<td>Jinja</td>
<td>154</td>
<td>0</td>
<td>5</td>
<td>159</td>
</tr>
<tr>
<td>Kabale</td>
<td>88</td>
<td>50</td>
<td>11</td>
<td>149</td>
</tr>
<tr>
<td>Kampala</td>
<td>499</td>
<td>253</td>
<td>113</td>
<td>865</td>
</tr>
<tr>
<td>Masaka</td>
<td>34</td>
<td>39</td>
<td>16</td>
<td>89</td>
</tr>
<tr>
<td>Mbale</td>
<td>24</td>
<td>13</td>
<td>5</td>
<td>42</td>
</tr>
<tr>
<td>Mbarara</td>
<td>37</td>
<td>13</td>
<td>30</td>
<td>80</td>
</tr>
<tr>
<td>Mukono</td>
<td>1</td>
<td>37</td>
<td>8</td>
<td>46</td>
</tr>
<tr>
<td>Soroti</td>
<td>39</td>
<td>40</td>
<td>3</td>
<td>82</td>
</tr>
<tr>
<td>Tororo</td>
<td>56</td>
<td>32</td>
<td>8</td>
<td>96</td>
</tr>
<tr>
<td>Total</td>
<td>955</td>
<td>492</td>
<td>205</td>
<td>1652</td>
</tr>
</tbody>
</table>

Table 6.1: Source availability from inventories by town

![Figure 6.1: Percentage distribution of sources by town and total](image-url)
The numbers and types of water show wide variation between the towns. Although Kampala had the highest number of sources identified, the difference is less than may be expected from the population data shown in table 4.2. The number of sources in Kampala is only five times greater than the next largest town (Jinja) which had only a tenth of the population. The town with the third highest number of sources, Kabale, had less than six times fewer sources than Kampala, despite a population that was 26 times smaller.

A correlation using the Pearson correlation statistic was carried out to investigate the relationship between the total number of water sources and population of each town. The null hypothesis was that no relationship existed. The results of this analysis did not yield results significant at the 95% level and therefore the null hypothesis was accepted.

There was considerable intra-urban variation in the number of sources. A detailed breakdown of source availability by different Parishes in each town is shown in Annex 19. The relationship between the total number of sources available in each Parish and Parish population and Parish socio-economic status were analysed to investigate if any relationships existed. In both cases, the null hypothesis was that there would be no significant relationship to the total number of sources identified within a Parish.

The relationship between socio-economic status and total number of sources in each Parish was tested using the Pearson statistic of correlation. When taking the full data set from all towns, there was a significant relationship between socio-economic status and the number of sources available in a Parish, with increasing numbers of sources noted with decreasing socio-economic score \( (R= -0.288, p = 0.01) \). The null hypothesis was thus rejected and a relationship between Parish socio-economic status and sources available for households lacking a connection accepted.

When the data from each town were analysed individually, only Kampala was found to have such a significant relationship between socio-economic score and number of sources per Parish \( (R = -4.09, p = 0.01) \), with Masaka also showing a significant
relationship ($R = -0.646, p = 0.05$). Most other towns showed a negative relationship between socio-economic score and sources available, although Entebbe, Mbarara and Soroti showed a positive relationship. Thus the null hypothesis would be accepted in all cases except in Kampala and Masaka.

The data for total number of sources in a Parish and Parish population were analysed using the Pearson correlation statistic. When taking the full data set of all Parishes from the towns, there was an overall positive correlation between the population recorded and the number of sources available ($R = 0.31, p = 0.01$) and therefore the null hypothesis was rejected. When the data from each town was analysed individually, only Kabale ($R = 0.71, p = 0.01$) and Kampala ($R = 0.40, p = 0.01$) showed relationships between the population of the Parish and the number of sources significant at the 99% level. Mukono showed a negative relationship between population and numbers of sources, significant to the 95% level ($R = -0.95, p = 0.05$). In the other towns, weak positive relationships were found, but none were significant at the 95% level. Thus with the exception of Kabale, Kampala and Mukono, the null hypothesis is accepted.

6.2.1.2 Taps

Taps were classified into three principal types defined in relation to the mode of supply. Public (or communal) taps are owned by a community or other group and are formally approved by the water supplier. NW&SC and Municipal Councils charged a discounted tariff to the managers of these taps.

The second class of taps were those where water was purchased from a household with a domestic connection to the piped water and were deemed as private connections by water suppliers. Purchase from private taps (or ‘on-selling’) is technically illegal in all water supplies.

The final class of taps was those provided by a landlord for use by a number of houses. These were somewhat different from the two previous types in nature, as they were taps provided for a discrete number of households living on a particular plot of
land and which tended to have restricted numbers of users. This class was primarily limited to Soroti and Jinja, although one tap of this type was also found in Kabale.

The data on piped water source availability is summarised in table 6.2 below. Mukono is excluded from this discussion as it has no formal piped water supply and has only one publicly available tap.

<table>
<thead>
<tr>
<th>Town</th>
<th>Public tap</th>
<th>On-selling from private tap</th>
<th>Landlord provided communal tap</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entebbe</td>
<td>9</td>
<td>14</td>
<td>0</td>
<td>23</td>
</tr>
<tr>
<td>Jinja</td>
<td>28</td>
<td>106</td>
<td>20</td>
<td>154</td>
</tr>
<tr>
<td>Kabale</td>
<td>83</td>
<td>4</td>
<td>1</td>
<td>88</td>
</tr>
<tr>
<td>Kampala</td>
<td>88</td>
<td>411</td>
<td>0</td>
<td>499</td>
</tr>
<tr>
<td>Masaka</td>
<td>32</td>
<td>2</td>
<td>0</td>
<td>34</td>
</tr>
<tr>
<td>Mbale</td>
<td>12</td>
<td>12</td>
<td>0</td>
<td>24</td>
</tr>
<tr>
<td>Mbarara</td>
<td>7</td>
<td>30</td>
<td>0</td>
<td>37</td>
</tr>
<tr>
<td>Mukono</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Soroti</td>
<td>7</td>
<td>1</td>
<td>31</td>
<td>39</td>
</tr>
<tr>
<td>Tororo</td>
<td>2</td>
<td>54</td>
<td>0</td>
<td>56</td>
</tr>
<tr>
<td>Total</td>
<td>268</td>
<td>635</td>
<td>52</td>
<td>955</td>
</tr>
</tbody>
</table>

Table 6.2: Class of taps found from inventories by town

The data show that the importance of each class of taps varied between the towns. In five towns (Entebbe, Jinja, Kampala, Mbarara and Tororo) ‘on-selling’ was the principal mode of communal piped water available. In the case of Kampala, Mbarara and Tororo, virtually all communal piped water was through ‘on-selling’, with the proportion being somewhat lower in Entebbe and Jinja. In the other four towns, the proportion of ‘on-selling’ was lower, with other forms of piped water supply being more important. Public taps represent a much higher proportion of piped water available in Masaka and Kabale and landlord provided taps being more common in Soroti. Public and landlord provided taps were more common in those towns with a
Municipal supply than those provided by NW&SC, although this is not the case for Masaka.

6.2.1.2 Point sources

Four types of protected point sources were identified in the inventories:

1. protected springs (these were the largest group of point sources, with almost two-thirds being in a state that enumerators felt required repair);
2. boreholes (the second most common type of protected point supply);
3. dug wells (differentiated into those with a sanitary means of withdrawal such as a handpump or windlass and those with no sanitary means of withdrawal); and,
4. rainwater catchment as a communal supply (this was only found in Kampala and represented a very small number of water sources).

There is a variation in availability of these sources between the towns as shown in table 6.3 below. Jinja is excluded from this discussion as no protected point sources were identified.

<table>
<thead>
<tr>
<th>Town</th>
<th>Protected springs</th>
<th>Borehole</th>
<th>Dug wells</th>
<th>Rainwater</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Good condition</td>
<td>Requiring repair</td>
<td>With handpump</td>
<td>No handpump</td>
<td></td>
</tr>
<tr>
<td>Entebbe</td>
<td>1</td>
<td>1</td>
<td>5</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Jinja</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Kabale</td>
<td>18</td>
<td>22</td>
<td>9</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Kampala</td>
<td>89</td>
<td>149</td>
<td>4</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Masaka</td>
<td>7</td>
<td>20</td>
<td>4</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>Mbale</td>
<td>2</td>
<td>5</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Mbarara</td>
<td>2</td>
<td>0</td>
<td>11</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Mukono</td>
<td>25</td>
<td>7</td>
<td>3</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Soroti</td>
<td>5</td>
<td>8</td>
<td>27</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Tororo</td>
<td>6</td>
<td>13</td>
<td>13</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>155</td>
<td>225</td>
<td>73</td>
<td>14</td>
<td>11</td>
</tr>
</tbody>
</table>

Table 6.3: Types of protected sources identified in inventories by town

The nature of the hydrogeology and topography largely explains the differences in protected source types noted between the towns. The springs are largely shallow,
regolith aquifers, although preferential flow paths are suspected to exist (Barret et al., 2000; Taylor and Howard, 2000). Protected springs predominate in the four towns with more pronounced relief. Three of the towns are on the shores of Lake Victoria (Kampala, Masaka and Mukono) where rainfall is less seasonal. Kabale, whilst not on the shore of Lake Victoria, also receives rainfall that is less directly demarcated into seasons because of its high elevation.

The topography of immediate urban environment in Mbale and Tororo is less pronounced, although both are close to hills and mountains. In the case of Mbale, which is close to Mount Elgon (the 5th highest mountain in Africa), springs emerge at higher elevations and have been widely exploited for rural water supply. The hydrogeology, at least in Mbale, appears to be more fracture dominated, which may account for the smaller numbers of springs. As both towns have large areas of low topography, dug wells and boreholes have been more viable as protected point sources.

In Soroti, the lack of springs is almost certainly related to the very flat topography that does not allow many springs to emerge and as a result the provision of protected point sources has had to rely on boreholes. Mbarara is in a region that suffers from frequent drought and therefore despite pronounced topography, only limited numbers of springs are found. The hydrogeology of the areas appears to be more dominated by fracture flow and therefore springs may be more restricted to areas where these reach the ground surface (Taylor and Howard, 2000). In Entebbe, a flatter topography has probably resulted in fewer springs.

6.2.1.3 Unprotected sources

These are only discussed briefly here as only very limited data on unprotected sources were collected and this was restricted to the inventory and water usage studies. Unprotected sources were found in all towns, although the numbers varied as shown in table 6.4 below.
Table 6.4: Types of unprotected sources identified in inventories by town

<table>
<thead>
<tr>
<th>Town</th>
<th>Unprotected spring</th>
<th>Unprotected scoop well</th>
<th>Surface water sources</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entebbe</td>
<td>4</td>
<td>0</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>Jinja</td>
<td>0</td>
<td>1</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Kabale</td>
<td>2</td>
<td>1</td>
<td>8</td>
<td>11</td>
</tr>
<tr>
<td>Kampala</td>
<td>69</td>
<td>27</td>
<td>17</td>
<td>113</td>
</tr>
<tr>
<td>Masaka</td>
<td>13</td>
<td>1</td>
<td>2</td>
<td>16</td>
</tr>
<tr>
<td>Mbale</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Mbarara</td>
<td>1</td>
<td>10</td>
<td>19</td>
<td>30</td>
</tr>
<tr>
<td>Mukono</td>
<td>5</td>
<td>3</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td>Soroti</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Tororo</td>
<td>6</td>
<td>2</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td>Total</td>
<td>104</td>
<td>48</td>
<td>53</td>
<td>205</td>
</tr>
</tbody>
</table>

The most common form of unprotected source identified were unprotected springs and these were found in all of the towns with the exception of Jinja. Unprotected scoop wells (very shallow excavations commonly found in swampy areas) were found more commonly in Kampala and Mbarara, but were less common elsewhere. Surface water sources were identified in all the towns that were on the shores of Lake Victoria (Entebbe, Jinja, Kampala, Masaka), had rivers within the urban boundaries (Mbarara and Kabale) or had ponds or swamps (Mbarara and Mbale). No surface water sources were found in Soroti, Tororo or Mukono, because there was less availability of surface water and these sources tended to be more remote from the major centres of settlement.

6.2.2 Household connections

Household connection rates were only calculated accurately for Kampala given the problems with obtaining connection data from both NW&SC and the Municipal Councils. In Kampala, a review of connections as of late 1998 indicated an overall rate of direct connection to the NW&SC supply of less than 20%. The number of households with a connection to the supply varied across the town and this is shown in Annex 20.
A Pearson’s correlation between the socio-economic status of Parishes and the percent of household with a direct connection was carried out, with a null hypothesis that that no relationship would exist. The correlation coefficient is significant at the 99% level of confidence ($R = 0.57$, $p = 0.01$). This relationship is shown below in figure 6.1.

![Figure 6.2: Relationship between socio-economic score and percentage of households with a connection for Parishes in Kampala](image)

The relationship between numbers of households with a connection and the socio-economic status of the Parish is not surprising, although as shown by Figure 6.2, the data does not fit the model particularly as shown by the dispersion around the trend line. The correlation statistic only refer to an overall linear relationship that can be defined between the two variables and is not a ‘goodness-of-fit’ measure. The use of ordinary least squares analysis was considered, but was not undertaken as the graphical representation of the dispersion provided more comprehensible description of the overall limited fit of the model.
The location of the Parish also influenced connection rates, with Parishes toward the centre of the City having average higher connection rates than Parishes further away from the centre, as shown in figure 6.2 below.

![Bar chart showing percentage of households with a connection by Division in Kampala](image)

**Figure 6.3: Percent of households with a connection by Division in Kampala**

The percentage of households with a connection was in the centre of the City, with lower percentages further away from the centre. However, as Central Division contains more Parishes of higher socio-economic status, there is obvious confounding.

### 6.3 Use of water sources by low-income households

#### 6.3.1 First choice water sources

The data on the reported use of different water sources for households in each study are shown in table 6.5. The data were analysed to evaluate whether there were any significant differences in the proportion of households selecting different types of water sources as their first choice source between the towns, with a null hypothesis that no significant difference would be seen. In addition, the data were analysed to investigate whether the organisation (NW&SC or Municipal Council) operating the piped water supply influenced selection. The null hypothesis was that there would be no significant difference. As the data were categorical, $\chi^2$ tests were used.
Proportionally more households used taps in Kampala and Masaka, which have a NW&SC piped water supply than in Soroti, which has a Municipal Council run supply. Analysis of the data showed that this difference was significant ($\chi^2 = 68.80$, $p < 0.001$, $df = 1$) and the null hypothesis was rejected. The number of households using taps was significantly greater in Masaka than in Kampala ($\chi^2 = 10.07$, $p = 0.002$, $df = 1$) and the null hypothesis was rejected.

### 6.3.2 Multiple source use

Multiple source use was common and was practised by 48.5% of households interviewed in Kampala, 56% of households in Masaka and 74.3% of households in Soroti. Data were also collected on diarrhoea within the previous week (this was not precisely defined) and the data from Kampala for reported diarrhoea and use of multiple sources of water were analysed to see whether an association existed using $\chi^2$. The null hypothesis was that no association would exist between reported incidence of diarrhoea and use of multiple sources of water. The tests gave a result that was significant at the 95% level ($\chi^2 = 4.33$, $p = 0.037$) and the null hypothesis was rejected.

Analysis was also undertaken to assess whether there was any difference in the use of multiple sources between towns where NW&SC operated the piped supply and where the Municipal Council operated the supply, with a null hypothesis that there would be no significant difference. The analysis showed multiple source use was significantly
more common in Soroti than in Masaka and Kampala ($\chi^2 = 33.56, p < 0.001, df= 2$) and the null hypothesis was rejected.

The data for the most commonly used sources from each town were analysed to assess whether the use of particular source types as a first choice water source influenced the use of multiple sources of water using $\chi^2$ tests with null hypotheses that no significant differences would be observed. As the data showed that selection of unprotected sources, dug wells and other sources was very uncommon as first choice sources, these were not analysed. The data were converted into a series of dummy coded categorical data in SPSS of households that used a source type and those that did not. In each case the coding was 1 = Used source, and 0 = did not use source. Where the enumerator had not provided any data regarding multiple source use, the record was excluded from analysis. The results of this analysis are shown in table 6.6 below.

<table>
<thead>
<tr>
<th>Source type</th>
<th>Town</th>
<th>Multiple source use</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Kamla</td>
<td>Multiple source use</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>No</td>
<td>Yes</td>
<td>$\chi^2$, p</td>
<td>No</td>
<td>Yes</td>
<td>$\chi^2$, p</td>
</tr>
<tr>
<td>Protected spring</td>
<td>No</td>
<td>311</td>
<td>383</td>
<td>37.67, p&lt;0.001</td>
<td>35</td>
<td>51</td>
<td>2.72, p=0.099</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>222</td>
<td>119</td>
<td></td>
<td>9</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Tap</td>
<td>No</td>
<td>262</td>
<td>146</td>
<td>51.73, p&lt;0.001</td>
<td>28</td>
<td>49</td>
<td>7.92, p=0.005</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>261</td>
<td>356</td>
<td></td>
<td>16</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Borehole</td>
<td>No</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

**Table 6.6: Results of analysis of multiple source use by principal first choice source**

The table of results shows that multiple source use was more common in households that used taps as a first choice source in Kampala and Masaka, significant at above the 99% level. In Soroti households using a borehole as a first choice more likely to use multiple sources and this was again significant above the 99% level.

The most frequently cited second choice source types were protected point sources in Kampala and Soroti, but unprotected sources in Masaka as shown in table 6.7 below. In Kampala households using a tap as a first source primarily used protected springs as a second source, whilst those using a protected spring as a first source used taps as
a second source (see Annex 18). In Soroti, households using either a borehole or a tap as a first choice source most commonly used a protected spring as the second source, although significant numbers of users of both types of source used a borehole as a second source. Where a borehole was the first choice source, significant use of taps was noted. Households using a protected spring as their first choice source used either a tap or a borehole as a second source.

<table>
<thead>
<tr>
<th>Source type</th>
<th>Kampala (N = 1035)</th>
<th>Masaka (N = 100)</th>
<th>Soroti (N = 140)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protected spring</td>
<td>345</td>
<td>6</td>
<td>44</td>
</tr>
<tr>
<td>Tap</td>
<td>122</td>
<td>9</td>
<td>23</td>
</tr>
<tr>
<td>Unprotected source</td>
<td>21</td>
<td>37</td>
<td>8</td>
</tr>
<tr>
<td>Borehole</td>
<td>0</td>
<td>0</td>
<td>29</td>
</tr>
<tr>
<td>Other</td>
<td>14</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>None</td>
<td>533</td>
<td>44</td>
<td>36</td>
</tr>
</tbody>
</table>

Table 6.7: Number of households selecting water source types as their second choice source

As shown in table 6.8, the use of a third or more external sources was not found in Masaka, was rare in Kampala (5.5% of households), but more common in Soroti (22.1%). The additional sources in Soroti were all boreholes, whilst in Kampala, protected springs were the most common, followed by taps with a few households using unprotected sources or tankers.
Evidence from the pilot study indicated that second sources were typically used several times per week and there was little overall differentiation in frequency of use between first and second choice sources. In order to evaluate the importance of different water sources, the number of households that report using each source as either their first choice or second choice was calculated. Where the same source type was used by a household as both a first and second source it was counted only once. The data are shown below in table 6.9.

Table 6.9: Aggregated use of principal source types by town
Little difference was found between the total number of households that use taps and those that use protected springs in Kampala, whilst in Soroti there was little difference in the proportion of total number of households that use of boreholes and springs, but use of taps is more limited. In Masaka, taps were used by a large majority of the low-income population, with other source use being less common and unprotected sources more commonly used than protected springs.

The data from Kampala were analysed to investigate whether there was a relationship between the proportion of households in a Parish using multiple sources of water and the socio-economic score of the Parish. This used the Spearman's rank correlation statistic, as the data was not continuous. The null hypothesis was that there would be no relationship between socio-economic score and multiple source use. There was a significant negative correlation between socio-economic score and the use of more than one source ($R_s = -0.663$, $p = 0.01$) and the null hypothesis was rejected, indicating that households in lower income Parishes were more likely to use multiple sources of water. This relationship is indicated in figure 6.3 below.

![Figure 6.3: Relationship between socio-economic score of Parish and percent of households using multiple sources in Kampala](image)

The data from Kampala were also analysed using the Spearman’s rank correlation statistic to see whether any relationship existed between socio-economic score of a Parish and the proportion of households using a particular source type as the first
choice source. The null hypotheses were that there would be no relationship between socio-economic score and use of taps or protected springs. No significant correlations were found between socio-economic score and the number of households using a particular source type as a first choice water source. The null hypotheses were therefore accepted.

The data of source type availability determined from the inventory were also analysed against patterns of use with a Spearman's rank correlation. The null hypotheses were that no relationships would be found between inventory data and use of either taps or protected springs. No significant relationships were noted and the null hypotheses accepted.

6.3.3 Use of vendors and rainwater

The use of vendors and rainwater collected at the home (termed as supplemental water) varied between the towns as shown figure 6.4. No households recorded using vendors in Masaka, but households in both Kampala and Soroti used vendors, although this was more common in Soroti. Rainwater collection was practised in most households in Masaka, by the majority in Kampala, but by relatively few households in Soroti. Relatively few households used improved methods of rainwater collection using guttering and a tank.

![Figure 6.5: Percent of households reporting use of vendors; rainwater, and those using guttering for rainwater collection from the water usage studies](image-url)
The data on use of vendors were analysed using $\chi^2$ to assess whether any differences were noted between the towns, with null hypotheses that no difference would be noted. The results of this analysis are shown in Table 6.10 below. The analysis showed that the greater proportion of households using vendors in Soroti compared to Kampala was significant at the 99% level and the null hypothesis was rejected.

<table>
<thead>
<tr>
<th>Comparison</th>
<th>Towns</th>
<th>No</th>
<th>Yes</th>
<th>$\chi^2$, p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vendor use</td>
<td>Kampala</td>
<td>855</td>
<td>178</td>
<td>7.21,</td>
</tr>
<tr>
<td>Kampala and Soroti</td>
<td>Soroti</td>
<td>102</td>
<td>37</td>
<td>0.007</td>
</tr>
<tr>
<td>Rainwater use</td>
<td>Kampala</td>
<td>341</td>
<td>692</td>
<td>38.39,</td>
</tr>
<tr>
<td>Kampala and Masaka</td>
<td>Masaka</td>
<td>3</td>
<td>96</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Use of guttering &amp; tank</td>
<td>Kampala</td>
<td>662</td>
<td>364</td>
<td>2.06,</td>
</tr>
<tr>
<td>Kampala and Masaka</td>
<td>Masaka</td>
<td>71</td>
<td>28</td>
<td>0.151</td>
</tr>
</tbody>
</table>

Table 6.10: Results of $\chi^2$ analysis for supplemental water

The data on rainwater use were analysed to investigate whether there was a difference in proportion of households using rainwater in Kampala and Masaka (Soroti was excluded as far fewer households used rainwater) with a null hypothesis that no significant difference would be found. As shown in Table 6.10 above, the difference was significant at the 99% level and the null hypothesis was rejected. The data on use of guttering and tanks between Kampala and Masaka were analysed, with a null hypothesis that no significant difference would be seen between the two towns. The analysis is shown in Table 6.10 above and shows that no significant difference was found and therefore the null hypothesis was accepted.

The data on vendor use in both Kampala and Soroti were also analysed to investigate whether the principal source types used as a first choice influenced the use of vendors, with null hypotheses that no significant differences would be seen. The results are shown in Table 6.11 below. In Kampala, no significant difference is seen in vendor usage between households using a tap or protected spring as their first choice source. In Soroti, the difference in use of vendors was significant at the 99% level when
comparing households using protected springs to users of boreholes and the difference between users of taps and boreholes was significant at the 95% level. In both these cases the null hypothesis was rejected. No significant difference was seen in use of vendors between households using taps or protected springs and in this case the null hypothesis was accepted.

<table>
<thead>
<tr>
<th>Town</th>
<th>Source types</th>
<th>No</th>
<th>Yes</th>
<th>$\chi^2$, p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kampala</td>
<td>Protected spring</td>
<td>288</td>
<td>52</td>
<td>1.15,</td>
</tr>
<tr>
<td></td>
<td>Tap</td>
<td>505</td>
<td>111</td>
<td>0.283</td>
</tr>
<tr>
<td>Soroti</td>
<td>Tap</td>
<td>16</td>
<td>8</td>
<td>4.16,</td>
</tr>
<tr>
<td></td>
<td>Borehole</td>
<td>55</td>
<td>9</td>
<td>0.041</td>
</tr>
<tr>
<td></td>
<td>Protected spring</td>
<td>27</td>
<td>20</td>
<td>0.56,</td>
</tr>
<tr>
<td></td>
<td>Borehole</td>
<td>16</td>
<td>8</td>
<td>0.452</td>
</tr>
<tr>
<td></td>
<td>Protected spring</td>
<td>27</td>
<td>20</td>
<td>11.40,</td>
</tr>
<tr>
<td></td>
<td>Borehole</td>
<td>55</td>
<td>9</td>
<td>0.001</td>
</tr>
</tbody>
</table>

Table 6.11: Results of $\chi^2$ analysis for use of vendors by first choice water source type

6.3.4 Use of water

Data were also collected on the use of water from each source. Use of water was ascertained for both first choice and second choice water sources. The use categories were as follows:

- Bathing
- Cooking
- Drinking
- Cleaning of house
- Laundry
- Water for animals
- Water for gardens
- Other use

The data were analysed to assess whether there was differentiation in the use of water from different sources that would indicate that a rationality factor was in operation. Of
principal interest was whether particular sources were used for drinking and cooking. The data for the major uses to which water from first choice sources was put are shown in figure 6.5 below and more detailed data are provided in Annex 18.

The use of water from different source types showed little differentiation in Kampala. Both protected springs and taps were used for drinking and cooking and for other domestic tasks whether chosen as first or second sources. This was also found in households where the first choice of water source was a tap and the second source a protected spring. There was, however, comparatively lower use of tap water for general household cleaning than water from protected springs, but this was not statistically significant. In Masaka, there is no significant differentiation in the use of water by source type, with all sources (including unprotected sources) being used for drinking and cooking.

In Soroti a differentiation in use was seen for first choice source with boreholes being more commonly used for drinking. The data were analysed using $\chi^2$ to investigate whether the difference was statistically significant. A dummy binary variable was created in SPPS to compare boreholes with other water source types ($1 = \text{borehole}, 0 = \text{other}$). The null hypothesis was that there would be no significant difference in the
percentage of households using water for drinking when collected from boreholes compared to households collecting water from either taps or protected springs. The test gave a result significant above the 99% confidence level ($\chi^2 = 20.81, p < 0.001, df = 1$) and the null hypothesis was rejected. All households using boreholes as a second source used this water for drinking. This indicates that in Soroti a rationality factor was in operation and anecdotal evidence indicates that this resulted from an initiative in the town to promote the use of borehole water for drinking on the basis of the poor quality of water in the town piped supply.

6.3.5 Reasons for source use

In Kampala and Soroti, data were collected on the reasons given by respondents for the use of different sources. The data of source selection reasons are shown in Annex 18. The data are described below initially in terms of overall reasons for source selection and then data are presented on measures of access, cost, quality and discontinuity as a means of capturing the importance attached to these specific indicators by users.

The summary responses obtained in relation to the reasons for selecting particular water sources as 1st and as 2nd sources are given in Tables 6.12 and 6.13 below. In these tables, data are provided on the percentage of households citing reasons for source selection by the source of water used. The columns labelled total refer to the total percentage of households giving the reason. It should be noted that the category ‘available’ did not imply the unavailability of any other source, but that the source was available for use and therefore does not reflect a forced choice.
<table>
<thead>
<tr>
<th>Town</th>
<th>Kampala</th>
<th>Soroti</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source/Reason</td>
<td>Protected spring</td>
<td>Tap</td>
</tr>
<tr>
<td>Distance</td>
<td>65.7</td>
<td>87.4</td>
</tr>
<tr>
<td>Cost</td>
<td>40.5</td>
<td>36.1</td>
</tr>
<tr>
<td>Quality</td>
<td>34.0</td>
<td>54.9</td>
</tr>
<tr>
<td>Reliability</td>
<td>31.7</td>
<td>40.5</td>
</tr>
<tr>
<td>Available</td>
<td>43.7</td>
<td>45.0</td>
</tr>
<tr>
<td>Only source</td>
<td>47.2</td>
<td>6.7</td>
</tr>
<tr>
<td>Only tap</td>
<td>29.3</td>
<td>-</td>
</tr>
<tr>
<td>Personal</td>
<td>3.8</td>
<td>6.4</td>
</tr>
<tr>
<td>Other</td>
<td>0.3</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Table 6.12: Percent reporting of reasons for selecting the first source choice by source type in Kampala and Soroti

<table>
<thead>
<tr>
<th>Town</th>
<th>Kampala</th>
<th>Soroti</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source/Reason</td>
<td>Protected spring</td>
<td>Tap</td>
</tr>
<tr>
<td>Distance</td>
<td>43.2</td>
<td>45.9</td>
</tr>
<tr>
<td>Cost</td>
<td>34.2</td>
<td>20.5</td>
</tr>
<tr>
<td>Quality</td>
<td>29.0</td>
<td>47.5</td>
</tr>
<tr>
<td>Reliability</td>
<td>40.9</td>
<td>30.3</td>
</tr>
<tr>
<td>Available</td>
<td>58.3</td>
<td>28.7</td>
</tr>
<tr>
<td>Only source</td>
<td>29.6</td>
<td>1.6</td>
</tr>
<tr>
<td>Only tap</td>
<td>19.7</td>
<td>-</td>
</tr>
<tr>
<td>Personal</td>
<td>3.8</td>
<td>16.4</td>
</tr>
<tr>
<td>Other</td>
<td>2.3</td>
<td>11.5</td>
</tr>
</tbody>
</table>

Table 6.13: Percent reporting of reasons for selecting a second water source by source type in Kampala and Soroti
For first choice water sources, 'distance' was overall the most common reason given in both Kampala and Soroti, with 'quality' the second most common reason. In Kampala 'distance' was the most common reason given for use of either a protected spring or tap, but was not for the other categories. In Soroti, 'distance' was the most common reason given for all source type categories, except 'other' (in this case boreholes), where 'quality' is the principal reason and was given by every household using this water source type.

In both towns, quality was the second most common response provided overall for using a second source. In Kampala, 'available' was the most commonly provided reason for use of protected springs as a second choice source and 'quality' was the most common for use of taps. In Soroti, 'quality' was the most commonly provided reason for using other sources of water (boreholes), with 'available' being the most common reason for use of protected springs and 'distance' for use of taps.

6.3.5.1 Model of source selection

The data were analysed through logistic regression models as a means of understanding why different sources were selected. The source use data were transformed into dummy binary categorical variables in SPSS to develop the models as follows:

1. Use of a tap as a first source (tap = 1; other sources = 0);
2. Use of a protected spring as a first source (protected spring = 1; other sources = 0);
3. Use of a borehole as a first source (borehole = 1; other sources = 0);
4. Use of a tap as a second source (tap = 1; other sources = 0);
5. Use of a protected spring as a second source (protected spring = 1; other sources = 0); and,
6. Use of a borehole as a second source (borehole = 1; other sources = 0).

These analyses were done for protected springs and taps in Kampala and for protected springs, taps and boreholes for Soroti, as the most commonly used sources. The results of the analyses are shown in table 6.14 below.
<table>
<thead>
<tr>
<th>Town</th>
<th>Model</th>
<th>Log estimate</th>
<th>Variables</th>
<th>Variable coefficient</th>
<th>SE</th>
<th>Wald</th>
<th>df</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Constant</td>
<td>0.58</td>
<td>0.19</td>
<td>9.39</td>
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<td>0.01</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Distance</td>
<td>0.62</td>
<td>0.18</td>
<td>12.4</td>
<td>1</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cost</td>
<td>-0.85</td>
<td>0.17</td>
<td>25.46</td>
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<td>1</td>
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<td>18.63</td>
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<td>source 1</td>
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<td>0.01</td>
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<td>0.01</td>
</tr>
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<td></td>
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</tr>
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<td></td>
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</tr>
<tr>
<td></td>
<td></td>
<td></td>
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<tr>
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</tr>
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</tr>
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</tr>
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<td>0.35</td>
<td>9.93</td>
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<td>0.02</td>
</tr>
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<td></td>
<td></td>
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<td>0.80</td>
<td>10.01</td>
<td>1</td>
<td>0.02</td>
</tr>
<tr>
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<td></td>
<td>Personal</td>
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<td>0.44</td>
<td>6.49</td>
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</tr>
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<td></td>
<td></td>
<td>Other</td>
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</tr>
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<td>Quality</td>
<td>-1.14</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td>Constant</td>
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<td>Only tap</td>
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<td>0.02</td>
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<td></td>
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<td>5.35</td>
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<td></td>
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<td>Quality</td>
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<td>0.52</td>
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<td>0.01</td>
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<td>Quality</td>
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<td>Soroti</td>
<td>Prot. Spring</td>
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<td>Constant</td>
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<td>0.56</td>
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<td>0.46</td>
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<td>source 2</td>
<td></td>
<td>Distance</td>
<td>1.87</td>
<td>0.58</td>
<td>10.35</td>
<td>1</td>
<td>0.01</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td>Quality</td>
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<td>0.01</td>
</tr>
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<td></td>
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<td>Reliable</td>
<td>-1.98</td>
<td>0.63</td>
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<td>0.01</td>
</tr>
<tr>
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<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Only source</td>
<td>-1.29</td>
<td>0.68</td>
<td>3.62</td>
<td>1</td>
<td>0.06</td>
</tr>
</tbody>
</table>

Table 6.14: Logistic regression models of reasons for source selection in Kampala and Soroti
The models for first choice sources in Kampala show that only a few factors appear to strongly influence the use of either a protected spring or tap rather than another source. Measures of access predominate with quality also important for taps and cost and reliability for protected springs. In the models for second choice water supplies, the same reasons are noted for each source type.

The models for first choice source selection in Soroti show that quality is the principal determining factor in the selection of a borehole. The factors influencing choice of tap or protected spring are remarkably similar and include measures of access and quality. For the models for second choice water sources, quality and reliability are the factors of importance when selecting a borehole. The reasons for selecting a tap as a second source related to access and for protected springs the factors include both access related factors as well as service quality.

6.3.6 Relationships between reasons for source use and source type

The data on source selection reasons were analysed to investigate whether there were any significant differences between Kampala and Soroti and also to investigate whether there were any significant associations between reasons for source selection and the type of sources used. The data were analysed using $\chi^2$.

6.3.6.1 Differences between Kampala and Soroti

The analysis was only performed of those reasons that were provided most commonly in each town. When investigating the differences in reporting for particular source types, only the data for protected springs and taps could be analysed between the two towns, as there were very little data for unprotected springs and the water source types included under 'other' sources were very different in the two towns. The null hypotheses were that no significant difference would be found in reporting of each reason between the two towns. The results of the analyses between the two towns are shown in table 6.15 below.
Table 6.15: Results of $\chi^2$ for reasons given for selection of first water sources in Kampala and Soroti

<table>
<thead>
<tr>
<th>Reason</th>
<th>All 1\textsuperscript{st} sources</th>
<th>All 2\textsuperscript{nd} sources</th>
<th>Protected spring source 1</th>
<th>Tap as source 1</th>
<th>Protected spring as source 2</th>
<th>Tap as source 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance</td>
<td>$\chi^2 = 0.91, p = 0.339$</td>
<td>$\chi^2 = 1.69, p = 0.194$</td>
<td>$\chi^2 = 0.06, p = 0.802$</td>
<td>$\chi^2 = 3.41, p = 0.065$</td>
<td>$\chi^2 = 0.14, p = 0.714$</td>
<td>$\chi^2 = 9.78, p = 0.002$</td>
</tr>
<tr>
<td>Available</td>
<td>$\chi^2 = 16.85, p &lt; 0.001$</td>
<td>$\chi^2 = 16.31, p &lt; 0.001$</td>
<td>$\chi^2 = 0.18, p = 0.672$</td>
<td>$\chi^2 = 0.11, p = 0.738$</td>
<td>$\chi^2 = 16.85, p &lt; 0.001$</td>
<td>$\chi^2 = 8.44, p = 0.004$</td>
</tr>
<tr>
<td>Only source</td>
<td>$\chi^2 = 0.03, p = 0.858$</td>
<td>$\chi^2 = 2.40, p = 0.121$</td>
<td>$\chi^2 = 0.07, p = 0.795$</td>
<td>$\chi^2 = 2.98, p = 0.084$</td>
<td>$\chi^2 = 0.47, p = 0.493$</td>
<td>$\chi^2 = 0.39, p = 0.531$</td>
</tr>
<tr>
<td>Cost</td>
<td>$\chi^2 = 1.62, p = 0.204$</td>
<td>$\chi^2 = 0.08, p = 0.774$</td>
<td>$\chi^2 = 0.32, p = 0.573$</td>
<td>$\chi^2 = 3.20, p = 0.074$</td>
<td>$\chi^2 = 0.46, p = 0.497$</td>
<td>$\chi^2 = 9.72, p = 0.002$</td>
</tr>
<tr>
<td>Quality</td>
<td>$\chi^2 = 9.99, p = 0.002$</td>
<td>$\chi^2 = 25.58, p &lt; 0.001$</td>
<td>$\chi^2 = 4.18, p = 0.041$</td>
<td>$\chi^2 = 2.86, p = 0.091$</td>
<td>$\chi^2 = 6.10, p &lt; 0.014$</td>
<td>$\chi^2 = 4.90, p = 0.027$</td>
</tr>
<tr>
<td>Reliable</td>
<td>$\chi^2 = 8.73, p = 0.003$</td>
<td>$\chi^2 = 9.85, p = 0.002$</td>
<td>$\chi^2 = 0.11, p = 0.744$</td>
<td>$\chi^2 = 0.09, p = 0.763$</td>
<td>$\chi^2 = 15.38, p &lt; 0.001$</td>
<td>$\chi^2 = 5.46, p = 0.019$</td>
</tr>
</tbody>
</table>

Only three reasons ('availability', 'quality' and 'reliability') show significant differences between Kampala and Soroti for both first and second choice water sources and the null hypotheses were rejected.

6.3.6.2 Reasons for selecting first choice sources and source type

The data on reasons for selecting a first choice source in Kampala and Soroti were analysed for each town separately to assess whether there were any significant differences between different source types. Only those sources most commonly used were included within the analyses. For Kampala these were taps and protected springs. All other data were excluded from the analysis and a dummy binary categorical variable was defined (1 = protected spring, 2 = tap). For Soroti three comparisons were made and dummy binary variables defined for each. These were:

- tap versus borehole (1 = borehole, 2 = tap);
- tap versus protected spring (1 = protected spring, 2 = tap); and,
- protected spring versus borehole (1 = protected spring, 2 = borehole)

All reasons except 'only tap' were included in the analyses. The null hypotheses were that no significant difference would be found in reporting of reasons between sources. The results of the analyses between the two towns are shown table 6.16 below.
In Kampala, significant differences are shown for reporting of three reasons (‘distance’, ‘only source’ and ‘quality’) and for these the null hypotheses were rejected. ‘Distance’ and ‘quality’ were provided by proportionally more households using taps and ‘only source’ by proportionally more households using protected springs.

For the comparison between taps and boreholes in Soroti, significant differences were seen in the reporting of three reasons (‘available’, ‘quality’ and ‘reliability’) and the null hypotheses were rejected. For the comparison between taps and protected springs, significant differences are found in the reporting of two reasons (‘distance’ and ‘only source’) and the null hypotheses were rejected. ‘Distance’ was given by proportionally more households using taps than households using protected springs and ‘only source’ was given by proportionally more households using protected springs than tap. For the comparison between taps and protected springs, significant differences are found for all reasons except ‘cost’. The null hypotheses were rejected for all reasons other than ‘cost’. Proportionally more households using boreholes reported ‘distance’, ‘quality’, ‘reliability’ and ‘available’ than households using protected springs. Proportionally more households using protected springs reported ‘only source’ than households using a borehole.
6.3.6.3 Reasons for use of second choice sources within Kampala and Soroti

The data on reasons for selecting a second source for households using multiple sources in Kampala and Soroti were analysed for each town separately to assess whether there were any significant differences between different source types. Only those sources most commonly used were included within the analyses. The same set of dummy binary categorical variables and the null hypotheses were the same as for first choice sources. The results of the analyses between the two towns are shown table 6.17 below.

Table 6.17: Results of $\chi^2$ tests of reasons for selecting second choice sources by source type in Kampala and Soroti

<table>
<thead>
<tr>
<th>Reason</th>
<th>Kampala</th>
<th>Soroti</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Protected spring and tap as source 2</td>
<td>Tap and boreholes as source 2</td>
</tr>
<tr>
<td>Distance</td>
<td>$\chi^2 = 0.37, p = 0.541$</td>
<td>$\chi^2 = 9.06, p = 0.003$</td>
</tr>
<tr>
<td>Cost</td>
<td>$\chi^2 = 7.71, p &lt; 0.001$</td>
<td>$\chi^2 = 7.11, p = 0.008$</td>
</tr>
<tr>
<td>Quality</td>
<td>$\chi^2 = 14.59, p &lt; 0.001$</td>
<td>$\chi^2 = 1.25, p = 0.264$</td>
</tr>
<tr>
<td>Reliability</td>
<td>$\chi^2 = 4.00, p = 0.046$</td>
<td>$\chi^2 = 3.41, p = 0.065$</td>
</tr>
<tr>
<td>Available</td>
<td>$\chi^2 = 31.14, p &lt; 0.001$</td>
<td>$\chi^2 = 0.82, p = 0.366$</td>
</tr>
<tr>
<td>Only source</td>
<td>$\chi^2 = 40.34, p &lt; 0.001$</td>
<td>$\chi^2 = 2.53, p = 0.112$</td>
</tr>
</tbody>
</table>

In Kampala significant differences were found in reporting of all reasons except 'distance' and the null hypotheses were rejected for these reasons. 'Quality' was given by proportionally more households using taps than protected springs. All the other reasons were given by proportionally more households using protected springs than taps.

In Soroti, the comparison of households using taps and boreholes found significant differences in reporting of two reasons ('distance' and 'cost') and the null hypotheses were rejected. Proportionally more households using taps gave these reasons than those using boreholes. The comparison of households using protected springs and taps found significant differences in reporting of four reasons ('distance', 'quality',...
‘available’ and ‘only source’) and the null hypotheses were rejected. ‘Distance’ and ‘quality’ were given as reasons by proportionally more households using taps than those using protected springs. ‘Available’ and ‘only source’ were given as reasons by proportionally more households using protected springs than those using taps. The comparison of households using protected springs and taps found significant differences in reporting of three reasons (‘quality’, ‘reliability’ and ‘available’) and the null hypotheses were rejected. ‘Quality’ was given as a reason by proportionally more households using boreholes than those using protected springs, whilst ‘reliability’ and ‘available’ were given by proportionally more households using protected springs than boreholes.

6.3.6.4 Reasons for selecting a second source by first source type

The data for reasons given for using a second source were analysed using $\chi^2$ from households using multiple sources to investigate whether there were significant differences in the reporting of reasons for using a second source between households using different source types as their first choice source.

Only those sources most commonly used were included within the analyses, all other data were excluded from the analysis. The same dummy coded variable were used as described in section 6.2.6.3 above. All reasons except ‘only tap’ were included in the analyses. The null hypotheses were that no significant difference would be found in reporting of reasons for selecting a second source between households using different source types as a first choice source. The results of the analyses between the two towns are shown table 6.18 below.
In Kampala when households used a tap as their first choice source, significant differences in reporting were found for two reasons (‘available’ and ‘only source’) and the null hypotheses were rejected. Proportionally more households using a protected spring as a second source gave these reasons than those using a tap as a second source. When households used a protected spring as a first source, significant differences in reporting were found for two reasons (‘quality’ and ‘only source’) and the null hypotheses were rejected. Proportionally more households using a tap as a second source gave ‘quality’ as a reason than households using a protected spring and proportionally more households using a protected spring gave ‘only source’ as a reason than those using a tap.

In Soroti, when households used a borehole as their first choice source, significant differences are found in reporting of four reasons (‘distance’, ‘cost’, ‘quality’ and ‘only source’) and the null hypotheses were rejected. Proportionally more households using a tap as a second source gave ‘distance’, ‘cost’ and ‘quality’ than those using protected springs and proportionally more households using a protected spring as a second source gave ‘only source’ than those using a tap.
When households used a protected spring as their first choice source, significant differences are found in reporting of two reasons ('distance' and 'quality') and the null hypotheses were rejected. Proportionally more households using a borehole as a second source gave 'quality' as a reason than those using a tap and proportionally more households using a tap as a second source gave 'distance' as a reason than those using a borehole. When households used a tap as their first choice source, a significant difference is only found in reporting of 'quality' and the null hypothesis was rejected. Proportionally more households using a borehole as a second source gave 'quality' as a reason than those using a protected spring.

6.4 Costs of water

The cost of water was collected through three principal means: inventory, water usage study, and review of utility tariff. The first two means provided data on the price of water when purchased at the point of collection by users of communal sources. The review of tariff provided the charges levied by the utilities as a means of comparison.

6.4.1 Data from the inventories

Piped sources commonly required payment directly by the user with 82.2% of taps requiring some payment compared to only 4.1% of protected point sources and 3.4% of unprotected sources. Payment was required on a per container basis in most towns and this was typically per 20 litre Jerry can or per multiple Jerry can. However, in Soroti payment was usually required on a monthly basis.

6.4.1.1 Piped sources

The need to purchase water from public taps varied between the towns as shown in Table 6.19. This illustrates that payment was required at all public taps in Masaka and Tororo, whilst payment was required at the majority of public taps in Kampala, Mbale, Mbarara and Entebbe. Payment was not required at the majority of taps in Jinja, Kabale and Soroti. In the case of Kabale, this was because in all but two of the cases, the public taps are supplied by community-managed scheme and therefore payment is likely to be only in response to major repairs. For the landlord provided taps, payment was required at just over half the taps in Soroti, whilst in Jinja water had to be purchased at 40% of these taps.
<table>
<thead>
<tr>
<th>Town</th>
<th>Public taps</th>
<th>Private taps</th>
<th>Landlord taps</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entebbe</td>
<td>88.9%</td>
<td>100%</td>
<td>-</td>
</tr>
<tr>
<td>Jinja</td>
<td>39.3%</td>
<td>100%</td>
<td>40%</td>
</tr>
<tr>
<td>Kabale</td>
<td>2.4%</td>
<td>75%</td>
<td>0%</td>
</tr>
<tr>
<td>Kampala</td>
<td>68.2%</td>
<td>99.8%</td>
<td>-</td>
</tr>
<tr>
<td>Masaka</td>
<td>100%</td>
<td>100%</td>
<td>-</td>
</tr>
<tr>
<td>Mbarara</td>
<td>71.4%</td>
<td>96.7%</td>
<td>-</td>
</tr>
<tr>
<td>Mukono</td>
<td>-</td>
<td>100%</td>
<td>-</td>
</tr>
<tr>
<td>Soroti</td>
<td>28.6%</td>
<td>100%</td>
<td>51.6%</td>
</tr>
<tr>
<td>Tororo</td>
<td>100%</td>
<td>100%</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 6.19: Percent of taps requiring payment by type and town

Requirement to purchase water varied between the three different types of piped water recorded as shown in table 6.19 above. In 99.2% of cases of ‘on-selling’ water had to be purchased. Payment was less commonly required for water from public taps (48.9%) and from landlord provided taps (46.2%). The data from all towns were combined and analysed using $\chi^2$ to investigate whether any difference was found in requirement to pay by tap class. The null hypotheses were that no differences would be found. There was a significant difference between requirement to pay between private on-selling and other forms of piped Supply ($\chi^2 = 374.90$, $p <0.001$, $df = 1$). There was no significant difference in the requirement to pay between public taps and landlord provided taps ($\chi^2 = 0.13$, $p =0.719$, $df = 1$).

The data were analysed using $\chi^2$ to see whether there was a difference in the requirement to pay for water from taps between NW&SC and Municipal Council run water supplies. The null hypothesis was that no significant difference would be found in requirement to pay between the two forms of piped water supply management. In towns served by NW&SC, proportionally more households using taps paid for water from a tap than households using taps in towns where the piped water supply was provided by the Municipal Council. The test gave a result that was significant above the 99% confidence level ($\chi^2= 401.14$, $p<0.001$, $df = 1$) and the null hypothesis was rejected.
The cost of water from taps varied both between towns and between class of tap as shown in table 6.20 below. Kabale and Mukono were excluded from further analysis, as details of cost in each town were for only available for one tap. Soroti is discussed separately as the principal means of payment was on a monthly basis. Prices are quoted in Ugandan Shillings (USH) and not converted into US dollars or pounds sterling because the shilling is floated against the dollar and the dollar price of water varied more significantly than the Ugandan Shilling price.

<table>
<thead>
<tr>
<th>Town</th>
<th>Number taps</th>
<th>Minimum</th>
<th>Mean</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entebbe</td>
<td>20</td>
<td>50.0</td>
<td>50.0</td>
<td>50.0</td>
</tr>
<tr>
<td>Jinja</td>
<td>116</td>
<td>25.0</td>
<td>35.6</td>
<td>100.0</td>
</tr>
<tr>
<td>Kabale</td>
<td>1</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
</tr>
<tr>
<td>Kampala</td>
<td>450</td>
<td>17.0</td>
<td>46.5</td>
<td>100.0</td>
</tr>
<tr>
<td>Masaka</td>
<td>37</td>
<td>17.0</td>
<td>28.8</td>
<td>50.0</td>
</tr>
<tr>
<td>Mbale</td>
<td>14</td>
<td>25.0</td>
<td>29.7</td>
<td>50.0</td>
</tr>
<tr>
<td>Mbarara</td>
<td>33</td>
<td>50.0</td>
<td>75.8</td>
<td>100.0</td>
</tr>
<tr>
<td>Mukono</td>
<td>1</td>
<td>50.0</td>
<td>50.0</td>
<td>50.0</td>
</tr>
<tr>
<td>Soroti</td>
<td>5</td>
<td>25.0</td>
<td>41.6</td>
<td>50.0</td>
</tr>
<tr>
<td>Tororo</td>
<td>56</td>
<td>15.0</td>
<td>46.4</td>
<td>100.0</td>
</tr>
<tr>
<td>Total</td>
<td>733</td>
<td>15.0</td>
<td>45.0</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Table 6.20: Range and average costs of water in Ugandan Shillings from taps by town

The cost per Jerry can by tap type for all towns, excluding Soroti, is shown in Table 6.21 below. This shows that the lowest price was charged for water from landlord provided taps and the highest price for on-selling of water by households with a connection. Public taps were almost exactly half way between the two. A dummy categorical variable was defined as on-selling or other and the data analysed using a one-way ANOVA to investigate whether there was a significant difference in average cost. The null hypothesis was that average cost from on-selling would not be significantly greater than other forms of tap. The analysis showed that there was a
significant difference in the average price of water purchased from on-selling compared to other forms of taps ($f = 23.28$, $p < 0.001$, $df = 2$).

<table>
<thead>
<tr>
<th>Tap class</th>
<th>Number of taps</th>
<th>Minimum</th>
<th>Mean</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Public tap</td>
<td>109</td>
<td>17.0</td>
<td>36.6</td>
<td>100.0</td>
</tr>
<tr>
<td>On-selling</td>
<td>600</td>
<td>20.0</td>
<td>46.8</td>
<td>100.0</td>
</tr>
<tr>
<td>Landlord-provided</td>
<td>10</td>
<td>25.0</td>
<td>32.5</td>
<td>50.0</td>
</tr>
</tbody>
</table>

Table 6.21: Range and average costs of water per Jerrycan from taps by type in Ugandan Shillings (excluding Soroti data)

In Soroti, the inventory identified only 22 sources out of 82 as requiring payment. Of these, 16 required payment on a monthly basis. The average monthly cost was USH929.4, with a standard deviation of USH645.91 and a range of USH200.0 to USH3000.0.

6.4.2 Water usage study data

Data were collected during the water usage studies in Kampala and Soroti. Overall, 55.8% of respondents reported paying for water from their first choice source and only 27.1% of household using a second source of water reported paying for this. The data from the water usage studies shows that in Soroti, the majority of households (61.4%) reported paying for water from their first choice source and 50.0% from a second source. There was a variation in the requirement to pay by source type as shown in figure 6.6 below.
In Kampala, where water from first choice sources was purchased by the Jerrycan, the mean cost was USH 48.1 and for second sources, the mean was USH 64.0, indicating that the price of water had not varied in the two years between the inventory and the water usage study.

In Soroti, payment for first choice water source was primarily required on a monthly basis (69%), although significantly more households using taps as a first choice paid on a per Jerrycan basis. The average cost per month for water from first choice source was USH1213.8. The average monthly cost of water from taps was higher (USH10,100.00) than for protected springs (USH300.0) and boreholes (USH453.9). For second choice water sources, the majority of households reported paying on a monthly basis (69.2%) with piped water users tending to pay per Jerrycan. The average cost of water from second sources was USH2241.7. The average cost of water from taps was higher (USH7555.6) than for protected springs (USH350.0) and boreholes (USH566.7). The data show a significant difference to the costs reported within the inventory.
Households using vendors were asked how much they paid per Jerry can. In Kampala, the average cost per Jerry can was USH148.5 and in Soroti, the average cost of vendor water was USH120.6 per Jerry can.

6.4.3 Utility tariff

The cost of water when purchased by households is higher than the charges levied by NW&SC as shown in Table 6.22. In this table the second column relates to the charges by NW&SC and the third column to data collected in the inventories. This table illustrates that the cost of water for households purchasing tap water from public taps is between 3.5 and 7 times the charge collected by NW&SC from domestic connections and between 5 and 10 times the charge collected from public taps. Table 6.22 illustrates that in fact the average cost of water when purchased by households lacking a connection is equivalent to the highest charge levied by NW&SC on industrial users and frequently higher. No similar comparison was possible for the Municipal Council run supplies, as no records of their tariffs were available.

<table>
<thead>
<tr>
<th>Service</th>
<th>NW&amp;SC cost per Jerry can</th>
<th>Cost per Jerry can from inventories</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domestic connection</td>
<td>USH 14.4</td>
<td></td>
</tr>
<tr>
<td>Institutional</td>
<td>USH 17.8</td>
<td></td>
</tr>
<tr>
<td>Commercial (1st 500m3)</td>
<td>USH 24.7</td>
<td></td>
</tr>
<tr>
<td>Minimum price public tap</td>
<td>USH 9.4</td>
<td>USH 25.0</td>
</tr>
<tr>
<td>Commercial (501-1500m3)</td>
<td>USH 29.6</td>
<td></td>
</tr>
<tr>
<td>Commercial (&gt;1501m3)</td>
<td>USH 33.3</td>
<td></td>
</tr>
<tr>
<td>Mean price public tap (NW&amp;SC supplies)</td>
<td>USH 9.4</td>
<td>USH 36.6</td>
</tr>
<tr>
<td>Mean price on-selling (NW&amp;SC supplies)</td>
<td>USH 14.4</td>
<td>USH 46.8</td>
</tr>
</tbody>
</table>

Table 6.22: Price comparison for NW&SC supplied water

6.5 Continuity

6.5.1 Inventory data

Of the 1652 sources recorded in all the inventories, only 309 (18.7%) were recorded as experiencing any discontinuity in supply. Table 6.23 below shows that of the sources showing discontinuity, piped water sources are those that are most commonly affected. Unprotected sources showed less discontinuity and protected point sources the least.
There is variation in discontinuity between the different towns, with overall proportionally more sources showing at least some interruption in supply in Kabale, Mbale and Mbarara than in most other towns. In all towns proportionally fewer protected point sources show discontinuity than piped sources.

The frequency of discontinuity is shown in figure 6.7 below. Discontinuity is primarily recorded as being occasional, with over 70% of sources that experienced discontinuity having this frequency. Seasonal interruption was relatively common, but daily and monthly interruptions are far less common.

<table>
<thead>
<tr>
<th>Town</th>
<th>Total</th>
<th>Piped</th>
<th>Protected point</th>
<th>Unprotected</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entebbe</td>
<td>6 (13.6%)</td>
<td>5 (21.7%)</td>
<td>0 (0.0%)</td>
<td>1 (16.7%)</td>
</tr>
<tr>
<td>Jinja</td>
<td>35 (22.0%)</td>
<td>34 (22.1%)</td>
<td>-</td>
<td>1 (20.0%)</td>
</tr>
<tr>
<td>Kabale</td>
<td>79 (53.0%)</td>
<td>76 (86.4%)</td>
<td>3 (6.0%)</td>
<td>0 (0.0%)</td>
</tr>
<tr>
<td>Kampala</td>
<td>89 (10.3%)</td>
<td>67 (13.4%)</td>
<td>14 (5.5%)</td>
<td>8 (7.1%)</td>
</tr>
<tr>
<td>Masaka</td>
<td>6 (6.7%)</td>
<td>3 (8.8%)</td>
<td>3 (7.7%)</td>
<td>0 (0.0%)</td>
</tr>
<tr>
<td>Mbale</td>
<td>30 (71.4%)</td>
<td>20 (83.3%)</td>
<td>7 (53.8%)</td>
<td>3 (60.0%)</td>
</tr>
<tr>
<td>Mbarara</td>
<td>39 (48.8%)</td>
<td>21 (56.8%)</td>
<td>4 (30.8%)</td>
<td>14 (46.7%)</td>
</tr>
<tr>
<td>Mukono</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
</tr>
<tr>
<td>Soroti</td>
<td>9 (11.0%)</td>
<td>7 (17.9%)</td>
<td>1 (2.5%)</td>
<td>1 (33.3%)</td>
</tr>
<tr>
<td>Tororo</td>
<td>16 (16.7%)</td>
<td>12 (21.4%)</td>
<td>1 (3.1%)</td>
<td>3 (37.5%)</td>
</tr>
<tr>
<td>Total</td>
<td>309 (18.7%)</td>
<td>245 (25.7%)</td>
<td>33 (6.7%)</td>
<td>31 (15.1%)</td>
</tr>
</tbody>
</table>

Table 6.23: Discontinuity by source type and town from inventory data, with the percentage of the total of each source type and town with discontinuity shown in brackets
It should be noted that interruption in piped water was primarily recorded as being occasional, although all but one source with reported daily interruption were taps of some sort. Other sources typically showed seasonal interruption, although boreholes in particular were also recorded as having occasional interruption in supply.

### 6.5.2 Data from sanitary inspections

Discontinuity was included within the piped water sanitary inspection form as discussed in section 3.5.4. The data collected in each town are summarised below in table 6.24 and are also shown in Annex 12. The table includes data from inspections carried out on piped water supply for a whole Parish and data from the sanitary inspection format used for individual tapstands. In both cases, respondents were asked whether there had been any discontinuity in supply during the previous 10 days.
<table>
<thead>
<tr>
<th>Town</th>
<th>No. Inspections</th>
<th>Frequency reporting (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entebbe</td>
<td>12</td>
<td>17.0</td>
</tr>
<tr>
<td>Jinja</td>
<td>21</td>
<td>29.0</td>
</tr>
<tr>
<td>Kabale</td>
<td>18</td>
<td>6.0</td>
</tr>
<tr>
<td>Kampala</td>
<td>1110</td>
<td>13.5</td>
</tr>
<tr>
<td>Masaka</td>
<td>21</td>
<td>24.0</td>
</tr>
<tr>
<td>Mbale</td>
<td>176</td>
<td>21.0</td>
</tr>
<tr>
<td>Mbarara</td>
<td>29</td>
<td>59.0</td>
</tr>
<tr>
<td>Soroti</td>
<td>169</td>
<td>8.3</td>
</tr>
<tr>
<td>Tororo</td>
<td>119</td>
<td>9.2</td>
</tr>
<tr>
<td>Total</td>
<td>1677</td>
<td>14.7</td>
</tr>
</tbody>
</table>

**Table 6.24 Reported discontinuity in piped water systems by town**

The data suggest that discontinuity was found in most piped water supplies and was particularly common in Mbarara. Discontinuity showed both temporal and spatial variation, for instance in Mbale most of the discontinuity was found during the early stages of the surveillance activity when there had been damage to the treatment works resulting in rationing of the supply. The variation in reporting is illustrated by figure 6.9 below for Kampala.

![Figure 6.9: Percent reporting of discontinuity in Kampala by Division and quarter](image)
Figure 6.9 illustrates that discontinuity in supply reduced over the duration of the surveillance programme in Kampala, however, Nakawa and Rubaga Divisions continued to experience regular discontinuity in supply. Makindye Division showed initially low reported discontinuity, but this increased towards the end of the monitoring period. Similar results were found for other towns as shown in Annex 12.

Gravity fed systems in Kabale showed little interruption with only two systems having one inspection reporting discontinuity, which was equivalent to 8% of inspections carried on all gravity-fed supplies.

6.5.3 Water usage data

In the water usage studies in Kampala and Soroti, respondents were asked whether they ever experienced interruption in supply at their first or second choice sources (where used). The data are summarised in table 6.25 below and are shown in Annex 18.

<table>
<thead>
<tr>
<th>First choice sources</th>
<th>Household category</th>
<th>Town</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Kampala</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(N = 1035)</td>
</tr>
<tr>
<td>All households</td>
<td></td>
<td>49.1%</td>
</tr>
<tr>
<td>Households using protected spring</td>
<td></td>
<td>2.6%</td>
</tr>
<tr>
<td>Households using taps</td>
<td></td>
<td>76.0%</td>
</tr>
<tr>
<td>Households using unprotected spring</td>
<td></td>
<td>38.3%</td>
</tr>
<tr>
<td>Households using other source/borehole</td>
<td></td>
<td>6.7%</td>
</tr>
<tr>
<td>Second choice sources</td>
<td></td>
<td>Kampala</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(N = 502)</td>
</tr>
<tr>
<td>All households using 2nd source</td>
<td></td>
<td>20.7%</td>
</tr>
<tr>
<td>Households using protected spring</td>
<td></td>
<td>2.3%</td>
</tr>
<tr>
<td>Households using taps</td>
<td></td>
<td>71.3%</td>
</tr>
<tr>
<td>Households using unprotected springs</td>
<td></td>
<td>9.5%</td>
</tr>
<tr>
<td>Households using other source/borehole</td>
<td></td>
<td>50.0%</td>
</tr>
</tbody>
</table>

Table 6.25: Percent of households reporting discontinuity by source type for Kampala and Soroti from water usage studies

A greater proportion of households in Soroti reported discontinuity in their first choice source and second choice sources than in Kampala. The data shows that discontinuity was most commonly reported for taps than protected springs when used as a first or a second choice source in Kampala. Virtually all households in Soroti using a tap as a first choice source and all those using taps as a second choice source reported discontinuity and there were high levels of reporting of discontinuity from
households using boreholes. Few households reported discontinuity in protected springs.

The data from both Kampala and Soroti indicate that user experience of interruption is more significant for taps than when recorded during sanitary inspection, which included community interview. This may be because discontinuity only occurred occasionally, which may not have been captured in the sanitary inspection data.

Data on the frequency of discontinuity, when this occurred, were also collected in the water usage studies and are summarised table 6.26 below. More detailed data is provided in Annex 18.

<table>
<thead>
<tr>
<th>Level of interruption</th>
<th>Kampala (N = 508)</th>
<th>Soroti (N = 83)</th>
</tr>
</thead>
<tbody>
<tr>
<td>First choice source</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Daily</td>
<td>2.0%</td>
<td>2.4%</td>
</tr>
<tr>
<td>Weekly</td>
<td>14.6%</td>
<td>7.2%</td>
</tr>
<tr>
<td>Monthly</td>
<td>17.1%</td>
<td>25.3%</td>
</tr>
<tr>
<td>Seasonally</td>
<td>6.7%</td>
<td>18.1%</td>
</tr>
<tr>
<td>Occasionally</td>
<td>58.5%</td>
<td>47.0%</td>
</tr>
<tr>
<td>Second choice source</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Daily</td>
<td>1.9%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Weekly</td>
<td>14.3%</td>
<td>36.4%</td>
</tr>
<tr>
<td>Monthly</td>
<td>14.3%</td>
<td>25.0%</td>
</tr>
<tr>
<td>Seasonally</td>
<td>9.6%</td>
<td>11.4%</td>
</tr>
<tr>
<td>Occasionally</td>
<td>46.2%</td>
<td>27.3%</td>
</tr>
</tbody>
</table>

Table 6.26 Reported frequency in discontinuity for Kampala and Soroti from water usage studies

The data indicate that Kampala water sources do not suffer regular discontinuity and when this occurs it tended to be only occasional. The data for weekly interruption in supply for taps from the water usage study is similar to that identified through sanitary inspection suggesting that the former provided a reasonable estimate of user experience. In Soroti, discontinuity occurred either every month or occasionally for first choice sources, but was often found on a weekly basis for second choice sources. This indicates that discontinuity occurred more regularly in Soroti than Kampala and indicates an overall lower level of supply adequacy than in Kampala.
6.6 Evidence of leakage

Data on leakage were gathered through the use of sanitary inspections in piped water supplies. This was only done when using the Parish-wide sanitary inspection form and these data were not included when inspections were only performed on individual tapstands. The data reported therefore only cover the period from July 1998 to December 1999. As noted in Section 3.6.4, the sanitary inspection data related to leakage are qualitative and are not an attempt to provide a quantitative estimate of physical losses. During the period of study very limited attempts were made by managers of piped water supplies to assess leakage and this was restricted to the NW&SC supplies.

6.6.1 NW&SC and Municipal supplies

The data for leakage from sanitary inspections carried out are summarised in table 6.27 below and shown in Annex 12. This shows that 32% of all sanitary inspections of NW&SC and Municipal supplies indicated signs of leakage within Parishes. There is significant variation between the towns with leakage being more commonly identified in Mbale, Kampala, Kabale and Jinja than the other towns. When aggregating the data for towns with a NW&SC supply, 33% of inspections showed evidence of leakage and for aggregated data for the Municipal Council run supplies this was 29%.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Kampala</td>
<td>49</td>
<td>52</td>
<td>50</td>
<td>16</td>
<td>19</td>
<td>16</td>
<td>35</td>
</tr>
<tr>
<td>Mbale</td>
<td>50</td>
<td>48</td>
<td>45</td>
<td>50</td>
<td>50</td>
<td>48</td>
<td>48</td>
</tr>
<tr>
<td>Soroti</td>
<td>31</td>
<td>36</td>
<td>47</td>
<td>20</td>
<td>4</td>
<td>0</td>
<td>22</td>
</tr>
<tr>
<td>Tororo</td>
<td>-</td>
<td>20</td>
<td>24</td>
<td>0</td>
<td>0</td>
<td>17</td>
<td>12</td>
</tr>
<tr>
<td>Kabale</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>50</td>
<td>0</td>
<td>25</td>
<td>28</td>
</tr>
<tr>
<td>Masaka</td>
<td>-</td>
<td>-</td>
<td>11</td>
<td>-*</td>
<td>9</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>Mbarara</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>33</td>
<td>-</td>
<td>0</td>
<td>12</td>
</tr>
<tr>
<td>Jinja</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>25</td>
<td>50</td>
<td>0</td>
<td>29</td>
</tr>
<tr>
<td>Entebbe</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0</td>
<td>33</td>
<td>10</td>
<td>8</td>
</tr>
<tr>
<td>Total</td>
<td>47</td>
<td>48</td>
<td>47</td>
<td>19</td>
<td>20</td>
<td>16</td>
<td>32</td>
</tr>
</tbody>
</table>

* = only one inspection carried out

Table 6.27: Percent reported signs of leakage from sanitary inspection by quarter and town.
There was notable variation in the reported signs of leakage over the period of study in Kampala, with initially high rates declining markedly from the 2nd quarter in 1999. In Soroti reporting of leakage also reduced from this time and in Tororo, reporting shows marked variation between quarters. By contrast reporting in Mbale shows little variation over the period of reporting.

Within towns there was also some variation in reporting of leakage as illustrated by figure 6.10 for Kampala. Signs of leakage were reported more frequently in Nakawa and Rubaga Divisions. Makindye and Central Division both show fluctuating percentage reporting of signs of leaks, with Kawempe Division showing a consistently lower level of signs of leaks. Reporting of pipe breaks was also concentrated largely in Nakawa and Rubaga Divisions, with occasional problems noted in Makindye and Kawempe.

There was also an apparent variation in relation to proximity to treatment works. For instance, in Mbale, there was less variation in both Industrial and Northern Divisions (which are further from the treatment works) showing similar rates of reporting (over 50%) whilst Wanale Division (which was close to the treatment works) had a much lower reporting (25%). This suggests that the more distant and probably older infrastructure in both these towns was more vulnerable to leakage.
6.6.2 Gravity-fed piped water supplies

The sanitary inspections of gravity-fed water supplies also collected qualitative data on leakage. This was in respect to signs of leakage between the source and main tank, signs of leaks in the main supply and community reporting of pipe breaks. Of the 26 inspections carried out, there were no reported leaks between the source and the tank, 15% of inspections identified leaks in the main supply and in 8% the community reported pipe breaks in the previous 10 days. This suggests that the gravity-fed supplies were maintained reasonably well. It is also possible that the lower pressure in such systems made identifying signs of leakage more difficult.

6.7 Quantities of water

Data were collected for the quantities of water used by households during the water usage studies in Kampala, Masaka and Soroti. This therefore related only to the quantities of water collected by households without their own connection to the piped water supply. The data are summarised in table 6.28 below.

<table>
<thead>
<tr>
<th>Town</th>
<th>Mean</th>
<th>Standard deviation</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kampala</td>
<td>18.6</td>
<td>10.1</td>
<td>2.5</td>
<td>100.0</td>
</tr>
<tr>
<td>Masaka</td>
<td>17.9</td>
<td>7.9</td>
<td>5.0</td>
<td>40.0</td>
</tr>
<tr>
<td>Soroti</td>
<td>20.0</td>
<td>12.0</td>
<td>6.7</td>
<td>80.0</td>
</tr>
</tbody>
</table>

Table 6.28: Average and range of volumes of water collected in litres per capita per day for Kampala, Masaka and Soroti

The data showed that there was little variation in the average volume of water collected per capita per day between the towns, with the average in each case being 20 litres per person per day or just below. The data were analysed to see whether there was a significant difference between the towns using a one-way ANOVA. The null hypothesis was that no significant difference would be found in mean volume collected between the two towns. The test produced a result that was not significant ($f = 0.78$, $p = 0.46$, $df = 2$).
The range of per capita volume collected varies more considerably, with much higher maximum quantities collected in Kampala and Soroti than in Masaka. This seemed to be due to the use of animal carts to collect water that was found in these two towns but not in Masaka. The minimum quantities in both towns are very low and must only reflect water collected for drinking.

The data were also analysed to see whether there was any significant variation between the per capita volumes collected between different source types and different towns for the same source type. The data are summarised in Table 6.29 below.

<table>
<thead>
<tr>
<th>Town</th>
<th>Protected spring</th>
<th>Tap</th>
<th>Unprotected spring</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kampala</td>
<td>18.50</td>
<td>18.72</td>
<td>17.19</td>
<td>18.1</td>
</tr>
<tr>
<td>Masaka</td>
<td>13.89</td>
<td>15.67</td>
<td>18.26</td>
<td>24.80</td>
</tr>
<tr>
<td>Soroti</td>
<td>20.90</td>
<td>25.31</td>
<td>12.86</td>
<td>19.10</td>
</tr>
</tbody>
</table>

Table 6.29: Volumes of water collected by source type from water usage studies

The source type data for Kampala were transformed into a dummy variable in SPSS relating whether the source was piped or non-piped (tap = 1; all other sources = 0). The data were analysed using a one-way ANOVA to assess whether there was any significant difference between piped and non-piped sources, with a null hypothesis that no significant difference would be found. The test gave a result that was not significant ($f = 0.35, p = 0.557, df = 1$).

In Masaka and Soroti, however, differences were seen in the quantities of water collected from different sources. In Masaka, differences are noted between the quantity of water collected by households using protected springs and taps compared to those collecting water from unprotected springs and 'other' sources. However, as noted in section 4.2.3, the majority of households used either taps or protected spring and the data for quantities of water collected from these two types of source were analysed using a one-way ANOVA to assess whether there was any difference in mean volumes collected. The null hypothesis was that the average volume of water
collected from protected springs compared to other source was not different. The test
gave a result that was not significant at the 95% level ($f = 3.88, p = 0.052, df = 1$).

In Soroti, quantities of water collected from unprotected springs were much lower
than for other sources, although the very small numbers of households using such
sources make any comparison difficult. As noted in section 4.2.3, the majority of the
population used taps or protected point sources and the data were transformed into a
dummy variable of piped and non-piped in the same way as for the analysis of data
from Kampala. The data were analysed using a one-way ANOVA, with a null
hypothesis no significant difference would be found in average volume of water
collected from the two sources. The test gave a result that was not significant ($f =
0.17, p = 0.190, df = 1$).

There were differences noted in the quantity of water collected from each source type
between the towns. The data for quantities of water collected from taps were tested
using an ANOVA, with a null hypothesis that no significant difference would be
found between the town. The test gave a result that was significant at the 95% level ($f
= 4.55, p = 0.011$) and the null hypothesis was rejected. The volume of water
collected from taps in Soroti was lower than for Kampala and Masaka, which had
similar average quantity of water collected. As Kampala has a NW&SC run piped
supply and Soroti a Municipal Council run piped water supply, a dummy variable was
defined in SPSS to represent piped water supply type (NW&SC = 1; Municipal = 2).
The data was analysed using a one-way ANOVA with a null hypothesis that no
significant difference would be found. The test gave a result that was significant at the
95% level ($f = 4.95, p = 0.026, df = 1$) and the null hypothesis was rejected.

The average quantity of water collected from protected springs appeared to vary
between the towns and the data were analysed using a one-way ANOVA, with a null
hypothesis that no significant difference would be found. The tests gave a result that
was not significant at the 95% level ($f = 2.80, p = 0.062$).
Chapter Seven

Discussion of results

7.1 Introduction

This chapter provides a discussion of the results obtained from the study undertaken in Uganda. This discussion will focus on three key areas:

1) Discussion of the findings from the surveillance activities in Uganda to explain variations noted and implications for the validity of the findings and the methods used;

2) To review the evidence from Uganda of the management value of the data generated and the linkage between this data and improvement in water supply; and,

3) Drawing on the above, to discuss the robustness of the indicators reviewed and assess their application within surveillance programmes.

7.2 Institutional framework

The institutional model adopted in Uganda reflects the general recommendations that
the surveillance function should be undertaken by an independent body (WHO, 1993). It also reflected the role of the Ministry of Health within Uganda as the national body taking responsibility for environmental health.

The use of environmental health staff working in Municipal Councils to undertake field activities for surveillance reflected the decentralisation of health and other social services to District and lower levels of local Government. Although the local Governments fell under the overall remit of the Ministry of Local Government, the role of the other national Government bodies was to provide policy guidance and technical support for the delivery of services. In the case of environmental health this was Ministry of Health. A strong relationship already existed between the Ministry of Health and local environmental health staff, which ensured that development of best practice in surveillance could be supported.

Within Uganda, there was initial pressure to work through the Directorate of Water Development (DWD) as they were mandated as the regulator of water resources and water supply in Uganda (Government of Uganda, 1995). Given the lack of health expertise in DWD, such an approach would have failed to incorporate public health as a central component of surveillance. Furthermore, in urban areas with a NW&SC supply, Municipal Authorities did not have any staff in the water sector, which would have severely limited the potential for field activities and the use of data to develop appropriate interventions to improve water supplies at a local level.

Whilst it may have been possible to use DWD as the national co-ordinating body for surveillance through their role as the sector regulator, it is unlikely that the strong links that were made between national and local bodies could have been successfully formed. Indeed, subsequent developments within the water and sanitation sector have highlighted the difficulties in making functional links between DWD at a national level and local environmental health staff (Paul Luyima 2001, personal communication).

The institutional relationships at national levels in Uganda were significantly enhanced by the regular round table stakeholder consultations held with water supply
agencies, local Government, NGOs and donor organisations. This process allowed regular review of the progress with the surveillance programme and provided a forum within which to discuss the findings of the programme. Such consultation was shown to be important in ensuring that surveillance continued to maintain support from a wide range of organisations and this helped to lead to the subsequent desire to establish surveillance in rural areas.

The model used in Uganda of local Government taking responsibility for implementation of surveillance activities was successful as shown by the range and depth of data collected in the project. It is also shown by the increased ability of Municipal authorities to implement programmes to improve water supply and hygiene practices. Within developing countries, decentralisation of surveillance functions is recommended because this provides a mechanism for sustainability, which builds upon existing institutions and responsibilities for environmental health (Howard, 2002; Lloyd et al., 1991; Lloyd and Bartram, 1991; WHO, 1997; World Bank, 1993).

As noted by Howard (1997a) NGOs have undertaken some pilot surveillance activities in urban areas in Mexico and this approach is also being developed in some towns in Bangladesh (Han Heijnen 2001, personal communication). The use of NGOs in these cases has been primarily focused on support to the development of local Government capacity to undertake surveillance. Howard (1997a; 1997b) notes that problems may be found in handing over responsibility to local Government and NGOs need to develop well-formulated exit strategies.

In Uganda, the involvement of NGOs in implementation of surveillance would potentially have duplicated the role of local Government and would have risked deflecting Government interest away from surveillance implementation. The evidence from Uganda suggests that working directly with local Government is successful and there was little justification for use of NGOs in the surveillance programme given the role of the Ministry of Health. NGOs were, however, a key end-user of surveillance results and were important in developing strategies to improve water supplies and hygiene.

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7.2.1 Involvement of Communities

As noted in Section 1.5.2.2, there is increasing interest in developing methods for community-based monitoring of water quality and there has been some work related to this in rural areas (Breslin, 2000). Howard and Pond (2002) note that there are initiatives within South Asia to actively pursue the development of community-based water quality monitoring. Other work has addressed broader issues of water supply management and in particular sustainability in rural water supplies where community-management of water supplies remains the predominant model of water supply provision (Schordt, 2000). Community management of protected springs, boreholes and public taps (the latter being management of only part of the supply) is also common in urban areas and in particular within low-income communities (Ahmed and Hossain, 1997; Cotton and Taylor, 1994; Gelinas et al., 1997; Singha, 1996).

Despite the attraction of community-based monitoring of water supply as a means of strengthening community management, there remains a lack of proven methodologies and the focus remains on collaboration rather than transfer of responsibility. Lloyd and Helmer (1991) recommend undertaking surveillance in the field in collaboration with communities, but do not suggest it is feasible to transfer ultimate responsibility for routine monitoring. Bartram (1996) and Lloyd and Helmer (1991) note that involvement of communities should be encouraged through participation in inspections and as a target audience for results of surveillance activities. In the programme of study in Uganda, both these elements were built into the surveillance programme and work was also undertaken in developing simple tools to permit the direct involvement of communities in monitoring.

Anecdotal evidence from field staff indicated that the simple reporting mechanisms to communities resulted in increasing demand from communities for information regarding the quality of their water sources and household water. Field staff reported that communities appeared to appreciate the emphasis placed on practical recommendations for improving operation and maintenance of water sources and water-handling practices in particular. The improvements in household water quality noted in section 5.3 in many towns were related to this feedback of information regarding quality and linking this to hygiene education. In some towns, reductions in
sanitary risks of water sources, particularly protected springs, were also found to occur in response to feedback.

Much of the feedback was via simple monthly reports. Community meetings were also held and were linked to greater improvements in water quality and, in Soroti, to changes in water collection behaviour. However, these were time-intensive activities and therefore there were limitations in scaling up improvements that resulted from intensive discussion.

Tools that could be used by low-income communities for sanitary inspection linked to specific actions for maintenance were also developed, primarily for protected springs. These are shown in Annex 4. The use of these forms was applied most successfully in a pilot project to rehabilitate a small number of protected springs in high-density areas of Kampala and were linked to training for community operators (Howard et al., 2001a). As this pilot activity was only undertaken in the later stages of the project, it is impossible to evaluate whether this had a long-term impact on improved operation and maintenance, but initial evidence suggests that it is effective. Tools were also developed for boreholes and some initial thoughts given development of community monitoring tools for management of local piped networks, although in the latter case this is more complicated by the interaction between localised and broader supply problems (Ince and Howard, 1999).

7.3 Programme development

Lloyd and Bartram (1991), Lloyd and Helmer (1991) and WHO (1997) recommend the development of a phased approach for surveillance programmes, as this allows the methods and tools employed to be refined. The results of the fieldwork in Uganda support this approach. The phased approach allowed refinements to be made to the sanitary inspection forms and reporting to communities at early stages, which made subsequent implementation far easier. It was found that with all modifications to sanitary inspection and reporting forms benefited from small-scale piloting. Furthermore, as changes in approach meant that different data sets had to be matched, this was only feasible when the overall data sets were of a manageable size. The phased approach also allowed new data needs to be identified and strategies
developed for their acquisition, the most obvious example being the water usage studies. The phased approach also allowed lessons to be learnt in relation to intervention strategies and the overall advocacy approach, which were incorporated into the full programme.

This approach also allowed the national team to provide the field-based support to local teams following initial formal training in surveillance techniques. This is supported by previous work in surveillance programme development (Bartram, 1996). Experience showed that there was a need for more regular support in the initial stages, but that this reduced fairly rapidly within a short time, but needed to supported by periodic refresher training.

The practical nature of the training courses and selecting sites that were similar to those where work would be undertaken were also found to be useful by the participants, as noted in course evaluations. This was noted especially in relation to considering how the data would be used to develop intervention strategies. The inclusion of both water supply and environmental staff was found to encourage subsequent interaction. The development of better local interactions between surveillance and water supply staff is supported by the view of WELL (1998) for the need to encourage local partnerships in relation to water supply.

The first course run in Kampala proved more difficult as there were too many participants which was a particular problem in relation to the use of testing kits. Following this, numbers were more controlled and attempts made to limit the number of participants per kit to three or a maximum of four.

The approach to training also yielded significant benefits because all the courses, with the exception of the course in Kampala, provided opportunities for staff in different towns to interact and have peer-learning. Within Kampala, the presence of staff from different Divisions also facilitated this process. The collaboration extended beyond the surveillance programme and it was noted that surveillance was promoted in other forums involving environmental health staff, for instance in the regular urban council association meetings. The approach to refresher training, which allowed participants
to define what they wanted to address, was also found to be effective in resolving queries and in disseminating experiences between different groups of staff.

7.3.1 Local surveillance development and analytical resources
The programme used portable on-site testing equipment and was geared towards the use of this equipment to strengthen local Government staff in implementing surveillance activities. The majority of the interventions needed to improve microbial water quality required action by communities. The use of portable kits was found to enhance the potential for participation by community members and this is noted as only being possible when on-site testing approaches are used (Howard, 2002; Lloyd and Bartram, 1991; Lloyd and Helmer, 1991).

Decentralisation does have implications regarding the analytical ranges that can be included, and in general, the testing of a wide range of chemicals may not be feasible (Ongley, 1998). This was of a limited concern in Uganda because there was little evidence of widespread chemical quality problems in urban water sources, for instance as shown by a study in Kampala on the quality of protected springs (Hydrotech Consultants, 1995). There was, however, evidence of increasing nitrate in some protected springs in Kampala, but this was restricted to those in high-density areas (Barrett et al, 2000a).

As the water quality problems in Uganda were primarily related to poor microbial quality of alternative sources and household water and because so few households had their own connection to a piped water supply, the development of capacity to monitor chemicals was not a priority. Ongley (1998) notes that water quality monitoring programmes should establish the priorities in water quality and ensure that these needs are met rather than trying to obtain large sets of data of limited management value. The programme in Uganda supports this view. It is also clear, however, that in countries where chemical contamination is a major issue, for instance arsenic in Bangladesh, experience has shown that field-based kits may be necessary to achieve testing objectives (Rasmussen and Andersen, 2001).

Lloyd and Helmer (1991) and WHO (1997) suggest that surveillance programmes
should include the development of regional and national laboratories. Lloyd et al. (1991) state that regional laboratories should provide back-up services to local surveillance teams through calibration of equipment and technical advice, as well as having capacity for a wider range of analysis. In Uganda, discussions were held regarding the development of regional laboratories for the health sector to support surveillance activities. There was some support for this among senior health officials as previous attempts had been made to establish such facilities in early water and sanitation programmes. However, the funding for such facilities was not available nor were sufficient analysts available to staff such units. Furthermore, the calibration of the kits used in Uganda was found to be possible by the Municipal environmental health staff. The absence of major chemical problems in the country suggests that development of broader analytical capacity is not a priority until much wider implementation of local surveillance programmes is carried out (Barrett et al., 2000a; Hydrotech, 1995).

Previous attempts to establish surveillance in developing countries, for instance in Bangladesh, have concentrated on the use of regional laboratories (WHO/SEARO, 1996). However, when undertaking projects in Bangladesh, the author of this thesis noted that in fact relatively little testing was undertaken by these laboratories and it was uncertain whether the testing carried out yielded improvements in water supply quality for the poor. By contrast, Sarkar and Heijnen (2000) note that a small pilot project implemented in Rajshahi using the approach developed in Uganda delivered much greater improvements in water quality and sanitary conditions in low-income communities.

It is possible that regional laboratories may become important in the future in Uganda, although there is limited rationale for this to occur in the short-term given other priorities in the water sector, particularly in relation to encouraging greater access at household levels. Because the country is relatively small and has a reasonably good road network, it is possible that the need for wider testing could be achieved through use of central facilities to support the local surveillance network.

Central laboratories have often been a focus for the development of monitoring and
surveillance programmes, largely driven by a belief that these facilities would provide the impetus for implementation of monitoring programmes. Bartram (1996) notes that the development of a central laboratory to act as a reference laboratory providing a wide range of analyses, training services and undertaking research was successful in Peru. The evidence from Africa and Asia, however, is less convincing. For instance, in a project in Zimbabwe, a monitoring programme that placed a great emphasis on the use of an expensive central laboratory with only limited local activities had been established for urban supplies. This did not prove to be cost-effective and the overall number of samples analysed was low in relation to the potential for use of local testing using on-site equipment (John Lewis 1999, personal communication).

In Uganda, there were a number of laboratories available at a national level, although none dedicated to surveillance. The Ministry of Health had a public health laboratory based at the National Hospital in Mulago. This facility was able to perform analysis of pathogens and was indeed used in investigations regarding the cholera outbreak in 1997 and 1998 and thus could act as a reference laboratory.

DWD was also in the process of developing a national water laboratory. This laboratory maintained a principal focus on water resources monitoring, although it also undertook some analysis from drinking water supplies run by Municipal Councils. However, the actual numbers of sample remained limited and problems with sample deterioration, particularly in samples taken for microbiological analysis, were encountered. There were facilities for a broader range of analyses available at Makerere University, who undertook a range of research and consultancy work for donors and the Government. These resources were available to the Ministry of Health and one such laboratory was involved in some studies linked to this programme of work.

NW&SC had a central laboratory in Kampala and all samples analysed for microbiological quality were collected by a sampling team sent from Kampala or brought to the laboratory by water quality technicians from the individual supplies. This led to very limited analysis of water produced in most supplies and serious problems in sample preservation. During the field study in Uganda portable water
testing kits were provided to NW&SC and as a result the frequency of analysis increased. This proved to be effective and greatly increased the capacity of the organisation to undertake routine testing of their water supplies.

Although there is a good rationale for developing national laboratories, in Uganda the use of existing facilities was deemed more effective than construction of new and expensive infrastructure. This same conclusion was drawn in Ghana, where there were sufficient numbers of laboratories in the public and private sectors that could perform a reference function (WEDC and RCPEH, 1999).

7.4 Targeting the poor and urban zoning

An explicit objective of the surveillance programme in Uganda was to include assessments of poverty and vulnerability as core components of the surveillance programme design and to target activities in those areas deemed to be at greatest risk from water-related disease. As noted in Chapter 1, the poor are at greatest at risk from water-related disease and Lloyd et al. (1991) note that surveillance of water supplies as a preventive health measure should focus on these areas.

The project in Uganda was the first surveillance programme in urban areas of developing countries to explicitly incorporate poverty within the programme design to cover entire urban areas. Previous work in Peru addressed the development of a categorisation matrix for urban areas that allowed surveillance in Lima to identify more vulnerable areas and to include informal areas of very high density, low service provision and perceived high vulnerability (Lloyd et al., 1991). However, although the qualitative measures used provided a means of incorporating measures of vulnerability into the surveillance programme, they did not include a measure of poverty. The study in Uganda developed the initial ideas used in Peru, but used a quantitative measure of poverty. The project in Uganda showed how a specific poverty criterion can be used as a means for identifying poor groups and directing surveillance activities into those areas with low-income households.

Focusing on low-income communities raised distinct political and legal issues that must be resolved as these communities were often informal in nature. As the
surveillance function was a Government oversight role, there was an important issue as to whether the extension of such a function into settlements that are not accepted or sanctioned was justified. Surveillance could, for instance, be seen as inferring some form of acceptance of the settlement that the authority explicitly wishes to avoid. Howard (1997a) notes that this was a problem in Mexico City and that local Government support was only obtained once the communities concerned were recognised and sanctioned.

In Uganda there was initial resistance by many local Government officials (particularly in Kampala) to working in informal settlements despite a generally more pro-poor attitude of the Government. This was overcome partly because of Government policies that were geared towards improvement of existing settlements. It was also overcome because of the significant cholera epidemic, which principally affected poor communities and whose effects were felt in both formal and informal settlements. The fact that cholera had been absent from Uganda in epidemic form outside of refugee camps and conflict areas gave great impetus to addressing all the environmental health problems within the city.

The argument for the surveillance programme to focus on all low-income areas was based on the health needs of low-income communities. Furthermore, as local Government staff implemented the surveillance programme, it was possible to ensure that the surveillance function is not seen as a *de facto* recognition that would lead to *de jure* conferment of tenure. This has been noted by other workers as important when addressing the supply of services to the urban poor (Hardoy and Sattethwaite, 1989). The surveillance programmes supported the argument for incremental improvement in water supply rather than the application of utopian, but unachievable, targets (Kalbermatten and Middleton, 1999).

**7.4.1 The socio-economic index**

The socio-economic index used in the study provided a quantitative method for establishing a measure of relative wealth to be incorporated into the surveillance design. A decision was made at the outset that relative poverty was more important than measures of absolute poverty, which many commentators point to being more a
relevant measure when addressing access to services and understanding health differentials (Moser, 1995; Rakodi, 1995; Satterthwaite, 1997; Stephens et al., 1997; Wratten, 1995).

The use of a quantitative approach has some disadvantages in that it may not be so readily updated and changes in inter-census periods are often significant (Satterthwaite, 1997). There were some concerns regarding the accuracy of the index as this was based on data collected in the 1991 census and therefore potentially outdated. However, as the index was a relative measure of wealth, changes were not significant as most areas that were likely to rise in socio-economic status were already undergoing these changes in 1991. Townsend et al. (1992) note that in the UK relative scoring and weighting of variables does not change significantly over time. Subsequent research led by the author has updated the socio-economic categorisation of Parishes in Kampala, a process which illustrated relatively little change (Howard et al., 2002b). This indicates that the original approach was robust.

There were some problems with applying the index at the Parish level, which may include a relatively large population with extremes of wealth and poverty found in close proximity (Hardoy and Satterthwaite, 1989). However, the principal purpose was to use a measure of poverty as a means to direct more detailed subsequent data collection of water supply adequacy and user experience through water usage studies and it was therefore justifiable to use this approach. The subsequent data collection on water supply adequacy through the surveillance programme and the data from water usage studies provided much of the detailed assessment of coping strategies among the poor.

7.4.2 Zoning methodology

The zoning methodology was used as a rapid assessment tool for directing the resources of the surveillance programme as discussed in section 4.4. As the zoning incorporated elements of use of water from different sources as discussed in section 4.4, it allowed appropriate weighting of sources types to be visited for collection of samples for water quality analysis and sanitary inspection data. The use of the zoning methodology was to ensure that greatest attention was placed on vulnerable areas. In
Kampala, five times more sanitary inspections were carried out and almost 5 times as many water samples were analysed in Parishes of high priority compared to those of lower priority. All household water testing was carried out in Parishes of high priority.

As shown in section 4.4.1, the efficacy of this approach was demonstrated by the analysis of data from the cholera epidemic in 1997/98, which provides evidence that the approach was effective in identifying vulnerable groups. The relationship noted between multiple source use and diarrhoea incidence shown in section 6.3.2 further demonstrates the value of the differentiation of groups by mode of water source use.

The evidence from this study suggests that zoning is of particular use in larger urban areas where there are complex patterns of socio-economic status, population density and water supply arrangements. In these cases, it is important to be able to target the most vulnerable groups and understand water source use in order to target the surveillance resources into those areas where water supply is likely to have the greatest impact on health (Lloyd et al., 1991). This is consistent with the view of Timmerman and Mulder (1999) that monitoring programmes should have clear management objectives. In large urban areas, the use of zoning also helped to improve the cost-effectiveness of the surveillance programme.

The results from the study in Uganda suggest that the use of zoning may not be as valuable in smaller towns, although if financial resources to support surveillance were more limited there may be a stronger rationale for employing zoning in such towns. As the major cost of routine monitoring relates to the transport and staff time, the use of zoning would have offered more modest savings for the surveillance programme in smaller towns. The variety of water sources may also increase the benefits of zoning in terms of targeting which water sources should be tested.

The analysis presented in section 4.4.1 indicates that the use of a multi-criteria approach improves the reliability of the zoning methodology to predict vulnerability and provides a mechanism to capture the multi-faceted nature of such vulnerability. The lack of a significant relationship with socio-economic status alone indicates that
this is not sufficiently reliable, although a stronger case could be made for the use of numbers of household connections.

7.5 Water quality

The following sections provide a discussion of the results obtained from the water quality monitoring undertaken in Uganda and the implications of this in relation to other surveillance programmes. Sections 7.5.1 to 7.5.3 review the data from the Uganda study. Sections 7.5.4 to 7.5.6 review these findings with regard to the parameter used in water quality monitoring, sampling strategies, sanitary inspection and data analysis.

7.5.1 Utility piped water quality

7.5.1.1 NW&SC supplies

The data from the NW&SC supplies show that these had better water quality than the Municipal supplies. The evidence from the data analysis suggests overall better management of the NW&SC supplies, however, compliance rates of NW&SC supplies with microbiological guidelines used in Uganda were variable. The smaller NW&SC supplies showed lower rates of compliance, although the smaller number of samples taken from these systems will have lead to greater reductions in percentage compliance for single or small numbers of failures.

Although free chlorine does appear to have the expected protective value, it is interesting to note that only in Mbale was the association between absence of 0.2mg/l free chlorine and presence of thermotolerant coliforms significant at the 99% level and in Kampala significant at the 95% level. This analysis shows that placing greater reliance on free chlorine residual is not sufficient to guarantee an absence of microbial contaminants (Ashbolt et al., 2001; Payment et al. 1991; Payment, 1998). This is supported by the associations noted with sanitary risk factors in the models of contamination shown in section 5.2.4. The importance of localised risk factors highlighted in the logistic regression models in section 5.2.4 have important implications as in these cases the concentration and the time available are insufficient to allow inactivation. Thus it can be concluded that greater attention is needed on
preventive maintenance and reduction of sanitary risks (Howard, 2002; Ince and Howard, 1999).

The analysis in Section 5.2.4 shows that there was a significant association between total chlorine residual below 0.2mg/l and presence of thermotolerant coliforms in NW&SC supplies. This could suggest that short-term failure in disinfection was the cause of contamination. It should be noted, however, that the relationship between inadequate total chlorine and presence of thermotolerant coliform is statistically significant only in Kampala (99% level), Mbale and Mbarara (both 95% levels). Therefore, it is unlikely that treatment failure alone explains the presence of thermotolerant coliforms and that contamination in distribution also occurred. This is supported by the importance of sanitary risk factors noted in the logistic regression models.

The free chlorine data suggest that in the NW&SC supplies there were problems in maintaining adequate residuals as no supplies exceeded 70% compliance of samples with 0.2mg/l of free chlorine within a single quarter. All the NW&SC supplies had chlorination units, however, the data in section 5.2.2 shows that in Jinja, Mbarara and Tororo, the number of samples with at least 0.2mg/l total chlorine was relatively low. None of the other towns served by NW&SC supplies had 100% compliance with 0.2mg/l total chlorine suggesting that chlorination in all supplies was interrupted.

The data in section 5.2.2 show that interruption in chlorination at the treatment works could not solely explain the loss of free chlorine and that chlorine losses incurred in the distribution systems were more important. Problems were noted with poor cleaning and flushing of pipes within the Kampala system and would have been likely to be found in other NW&SC supplies. The data in section 5.2.2 also suggest that a significant amount of chlorine was lost because of evaporation and consumption in service reservoirs (Bailey and Thompson, 1996; Geldreich, 1996).

Loss of free chlorine is likely to have been caused in many cases by the consumption of free chlorine by ingress of contaminated water, which is supported by the strong association with sanitary risk factors noted in section 5.2.3. The loss of free chlorine...
in these conditions is expected. This is supported by the importance of interruption in the supply suggesting that ingress almost certainly does occur. Previous work has noted the importance of discontinuity in resulting in intrusion of contaminated water and in some cases pathogens (Clark et al, 1993a; Kirmeyer and LeChevalier, 2001).

Discontinuity will not always lead to ingress, as the pipes not delivering water to the tap are unlikely to be empty and in some cases will remain at higher pressure than surrounding soil water (Davison et al., 2002). In Uganda, the risk of ingress may be greater given the relatively wet climate and likely higher soil water pressure. It is perhaps of even greater concern when interruption to supply is common, as free chlorine will be less able to inactivate viral and protozoan pathogens that may enter with ingress water (Kirmeyer and LeChevalier, 2001; Payment, 1998).

Other factors that may have influenced the loss of free chlorine include the relatively long distribution systems. Losses of chlorine residual are far from uncommon in long distribution systems and have led to recommendations for booster or relay chlorination in piped water supplies (Bailey and Thompson, 1996; Geldreich, 1996). In addition, it is likely that there was biofilm development within the systems, as all the NW&SC supplies were taken from surface water sources, many of which were nutrient rich. This is noted by van der Kooij (1993) and Geldreich (1996) as being an important factor in biofilm development.

The data in section 5.2.2 show that performance in maintaining a free chlorine residual of 0.2mg/l in Kampala improved significantly over time. This occurred as a response to the ongoing pressure exerted by independent analysis being performed by the surveillance programme and the introduction of relay chlorination based on the recommendations of the surveillance programme.

Several of the NW&SC supplies showed weaknesses in supply management with relatively frequent discontinuity (Mbarara), signs of leakage (Mbale, Kampala and Jinja), pipe breaks (Mbarara) and mains pipe being exposed (Tororo, Mbarara and Entebbe) being reported. There was a significant correlation between risk score and contamination events, although as noted in section 5.2.4.2 the Spearman’s rank Rs
value was low and the data show significant dispersion around the trend line. Sanitary risk was higher when contamination was found as shown in figure 5.5, but the difference is relatively low. This suggests that the risk score was not an effective predictive tool for contamination.

7.5.1.2 Municipal Council systems

The supplies operated by Municipal Councils show more frequent isolation of thermotolerant coliforms, although the chlorine data indicate that chlorination at the treatment works was similar to many of the NW&SC supplies. The data for Soroti indicate that most contamination occurred within the distribution system, suggesting that preventive maintenance in distribution was weaker. This is shown by the inclusion of adequate free chlorine in the logistic regression model shown in Section 5.2.4. This suggests that microbial quality in Municipal supplies relied heavily on maintaining free chlorine residual rather than other aspects of maintenance. The correlation between risk score and contamination events was significant for Municipal supplies and the correlation statistic was greater than that found for NW&SC supplies. However, as noted in section 5.2.4.2 the correlation statistic was still of low value and the predictive value of risk score was limited.

In Soroti, the main service reservoir had not been cleaned since rehabilitation some years ago and on inspection was noted to contain substantial amounts of sediment. In Kabale, more significant problems were found with the treatment works, as the operator only visited the (under-sized) treatment works occasionally and did not have access to any dosing equipment for coagulant or chlorine. The depth of filter bed was also noted as being inadequate and simple turbidity control was frequently not performed. In both Kabale and Soroti, chlorine supplies often ran out and were further compromised by the lack of a functional back-up power supplies. During the period of study power supply from the main grid in Uganda was rationed resulting in power outages every second day. Furthermore, as these supplies relied on the Directorate for Water Development for major technical support, even minor breakdowns in electrical and mechanical controls resulted in lengthy delays.

In both Kabale and Soroti problems were noted with adequate staffing levels, as
neither had the full complement of staff required to run the systems and, in common with other local Government staff, they were frequently paid late and sometimes not at all. Discussions with the water staff in these local councils noted that limited revenue made operation difficult and the funds raised through taxation that should have been set aside for water supply operation were commonly diverted for other uses. Even ensuring access to vehicles for operation staff to visit treatment works, intakes and the distribution system was often problematic.

The surveillance programme did achieve some improvements in the Municipal Council run supplies. In Soroti, for instance, the public health and water supply sections of the Municipal council worked closely together to identify and resolve supply faults, an example being the repair of a major leak in a swampy area that caused a significant amount of contamination.

7.5.1.3 Comparing NW&SC and Municipal supplies

The statistical analysis of the microbial data indicates that the level of contamination in the Municipal supplies was significantly greater than the NW&SC supplies. Average sanitary risk scores, however, were lower in Municipal supplies than most of the NW&SC supplies. Furthermore the chlorine residuals were in general at least on a par with many of the NW&SC supplies and better than several of the NW&SC supplies. The microbial quality suggests that this was managed more effectively in the NW&SC supplies than the Municipal supplies, which is shown by the inclusion of the term 'type of supply' in the overall logistic regression model in table 5.15.

The problems faced by Municipal-run water supplies in Uganda are far from atypical of the water sector throughout Africa and many of the problems have been related to deteriorating operation and maintenance due to poor cost-recovery (Nixon, 1997; World Bank, 1993). This results in a vicious cycle as improvement in cost-recovery is hampered by the poor service that makes it difficult to persuade customers of the need for increases in tariff (WELL, 1998; World Bank, 1993). In Uganda, the inability to extend coverage and recover costs by Municipal Council meant that they were unable to perform the same level as the NW&SC supplies in terms of water quality control.
One of the key findings of the surveillance programme was that using a utility solely responsible for water supply (in this case NW&SC) was more effective than those operated by Municipal Councils with a wide range of responsibilities. Recommendations were made for the NW&SC to take control of operation in larger towns with a Municipal Council run supply and indeed both the Kabale and Soroti piped systems are now operated by NW&SC.

In both NW&SC and Municipal Council supplies, the analysis of data in Section 5.2 indicates that intervention strategies should be developed for improvement in the tertiary infrastructure through greater interaction between the utility and communities in maintaining such infrastructure. Improvements in treatment or chlorination may improve microbial water quality, but the problem in maintaining a residual concentration that would provide adequate protection suggests that this would be difficult to achieve and would not be effective in the long-term. This conclusion is supported by work in other African utility supplies. For instance, in an assessment of 20 urban piped water supplies in Ghana, localised risks predominated in causing contamination and in far fewer cases supply faults were noted (Ince and Howard, 1999).

7.5.2 Community-managed piped water supplies

The limited data available on the community-managed systems restrict meaningful discussion of the results. However, the available results indicate that the quality water was better than the protected springs, although not as good as boreholes. Operation and maintenance, as described by the sanitary inspection scores, showed fewer risks than other types of community-managed water sources.

The operation and maintenance of these water supplies was supported by the Municipal Water Office and it is likely that this led to lower sanitary risks than in other community-managed supplies when little external support was provided by water professionals. Although no data were collected on user perceptions of water supply in Kabale, the lower sanitary risks may have reflected a higher value placed on these supplies by the users, because they were more accessible than point sources. As the coverage of the town by Municipal supply in Kabale was very limited,
maintaining community-managed piped supplies was critical for communities with restricted alternatives easily available.

The lack of association of any sanitary risk factors with contamination in the distribution system shows that either there is contamination in the source water or that there was biofilm development (LeChevalier, 1999; WHO, 1996). Little information was available for the sources of water, although sanitary inspections were carried out and did not show particularly high risks to suggest a source water problem. Contamination was most commonly found in storage tanks that the sanitary inspections show to be in good external sanitary condition and therefore ingress would be expected to be limited. The storage tanks were, however, rarely cleaned and this may have allowed the development of biofilm, despite the source water being of a type that would be generally considered likely to be relatively nutrient poor (van der Kooij, 1993). However, as no analyses were performed on the biological stability of the water this conclusion is difficult to substantiate.

7.5.3 Point sources

7.5.3.1 Boreholes

The data from the boreholes illustrate that with the exception of Mbale, the microbiological quality of these sources is generally good and in the case of Soroti provided better quality water than the piped network. In general contamination, when found, was low and overall was lower than that of protected springs. The data showed that it is easier to protect microbial quality in boreholes. The boreholes appeared to have better operation and maintenance than protected springs, as shown by the low sanitary risk scores shown in section 5.31.

In general it can be assumed that the design and nature of boreholes with handpumps makes them less vulnerable to very rapid recharge that was noted as leading to contamination of the protected springs in Section 5.3.2. This is further supported by the analysis of the data using contingency tables, which suggests that it is sub-surface leaching of contaminants from latrines that represents the greatest risk of contamination of boreholes. Although two other factors – faulty drainage and
handpump being loose at the point of attachment – were included with latrine proximity in the final logistic regression model shown in section 5.3.1.1, the reporting of these was much lower than latrine proximity.

Studies by Chidaevenzi et al. (2000), Sobsey (1980) and Subrahmanyan and Bharaskan (1950) showed that the penetration of bacteria into the sub-surface in alluvial aquifers is limited to a travel time equivalent to 5-7 days. They further show that lateral breakthrough is limited to within 5m in most cases, although some studies have noted bacteria surviving up to 42 days in some groundwater environments. Even though extended survival may occur, the processes of attenuation will in most cases greatly reduce the concentration of bacteria (ARGOSS, 2002).

Research suggests that within a relatively short period of time a biologically active layer forms around the active layers of the latrine pit (i.e. those receiving faecal material) and forms a mat composed of bacteria and fungi (ARGOSS, 2002; Caldwell and Parr, 1937). Within 3 months this mat inhibits bacterial movement and within 7 months bacterial presence is largely restricted to the latrine. In Soroti and Tororo, which had regolith aquifer, the development of biologically active mats around latrines would explain why few thermotolerant coliforms were found in water samples taken from boreholes.

It has been noted that such processes vary with the nature of the subsurface and that local conditions may lead to significant breakthrough of bacteria (Lewis et al., 1982; Pyles, 1979). This explains why contamination was found more frequently in Mbale, where fracture aquifers appear to dominate in the tertiary volcanic geology. The flow rates and often complex flow paths in such a setting make control of microbial quality more difficult.

It can be concluded that for most towns in this study, water quality in boreholes is primarily related to the proximity of latrines and provided an adequate distance is maintained then significant microbial contamination is unlikely to occur. The evidence from this study suggests that a minimum of 10 metres is likely to be adequate in most cases, which was confirmed through studies to evaluate a
hydrogeological assessment of pollution potential (ARGOSS, 2002).

The restriction on location of on-site sanitation would probably not be adequate to control microbial quality in Mbale, where fracture aquifers appear to dominate in the tertiary volcanic geology. Contamination of boreholes in Mbale almost certainly also resulted from poor design. For instance in two cases the boreholes were located in swampy areas and one of these was sunk through a termite mound to avoid regular flooding. A third borehole had been located next to a surface water source and is likely to be drawing in contaminated surface water. Therefore, in all these cases, the potential for intake of contaminated surface water is expected to be high.

Although the study in Uganda indicates the importance of controlling the proximity of pit latrines, this is not necessarily the case in other developing countries. For instance, in Bangladesh where many tubewells fitted with handpumps are found in urban areas, construction techniques often increase the potential for direct ingress and aprons are commonly not found (Ahmed et al., 2002).

The analysis suggests two key findings of importance for improvement strategies. Firstly, the quality of boreholes is generally very good and represents only limited cause for concern in most towns. This suggests that the promotion of boreholes as a viable alternative source of water for low-income communities is a realistic option and in Soroti the water quality data were used as the basis of a campaign to promote the use of borehole water for drinking. Secondly, the major cause of concern is the proximity of latrines, thus requiring adequate lateral separation. However, this is undoubtedly affected by the results from Mbale where the geology appears to have exerted an important influence.

Simple hydrogeological assessment methodologies are available for the correct siting of on-site sanitation and boreholes and have been applied in both Uganda and Bangladesh (ARGOSS, 2001). However, the surveillance programme in Uganda has also shown that it is effective in identifying the likely impact of sanitation on groundwater and in allowing the development of at least qualitative estimates of safe separation distances.
7.5.3.2 Protected springs

The results from analysis of water quality at protected springs show that these are more commonly contaminated than boreholes and that the numbers of indicator bacteria were typically much higher. The case studies presented in section 5.3.2 indicate that most protected springs consistently showed microbial contamination. The risk of consuming water from protected springs can therefore be assumed to be significantly higher than the risk posed by boreholes or piped water. This is a particular concern given the data shown in section 6.3 that protected springs are widely used by households in low-income areas of Kampala. Nasinyama et al. (2000) showed that use of protected springs in Kampala was related to higher incidence of acute diarrhoeal disease.

The data shown in section 5.3.2 also indicate that operation and maintenance was relatively poor and worse than for boreholes on the basis of the high sanitary risk scores. The importance of protection factors, such as eroded backfill areas, faulty diversion ditches, faulty masonry, absence of fences and flooding of the collection area, noted in the case studies in section 5.3.2.2 to 5.3.2.4 point to the importance of poor maintenance of sanitary completion measures.

In Kampala, many of the protected springs were found in high-density settlements as shown in sections 5.3.2.2 and 5.3.2.4 and the quality of protected springs in high-density areas was worse than those in low-density areas. The combination of poor maintenance and high faecal loading explains why springs in high-density areas tend to have much higher levels of contamination. This poor operation and maintenance of the springs suggest that although valued as a source of water, communities have a limited perception of the need for routine maintenance.

The greater choice of water sources in high-density areas may lead to poorer maintenance of the springs as piped water infrastructure is better developed and often greater numbers of household connections are found. Lower-density areas have seen much more limited and later development of piped water infrastructure and, therefore, protected springs may have been more critical for water collection than in high-density areas.
The analysis of the data from the case study 3 (section 5.3.2.4) shows that the microbial quality deteriorates rapidly and significantly following rainfall events. This emphasises the vulnerability of the shallow groundwater to faecal contamination and a rapidly emerging public health risk following rainfall events (Barrett et al., 2000a; Barrett et al., 2000b; Howard et al., 2002b; Wright, 1986). The strong association between microbial contamination with both short period rainfall and deterioration in the protection measures in the immediate area of the source, supports a theory of rapid recharge and consequent deterioration in microbial quality in response to rainfall. This suggests that entry of recharge water occurs close to the spring with limited opportunities for attenuation and is likely to result both from localised interflow through preferential flow paths and direct ingress through poorly maintained infrastructure (Barrett et al., 2000a; Howard et al., 2002b).

In case study 3 (section 5.3.2.4), stagnant surface water and solid waste material both appear to be more important than latrines as sources of these bacteria. However, it is noted that thermotolerant coliform presence is influenced more by latrine proximity than faecal streptococci. The importance of both these factors would be supported by the limited evidence of latrines identified in the assessment undertaken as part of this case study. This leads to indiscriminate disposal of faeces into the environment and concentration of faecal matter in drainage channels, solid waste dumps and surface water.

It is also likely that a significant proportion of this faecal matter may be animal rather than human in origin. Both wild animals (rodents etc) and domestic animals (in particular goats and chickens) are found in low-income areas and animal faecal contamination has been shown to be present in the shallow aquifer in Kampala (Barrett et al., 2000b). However, inclusion of population density in the logistic regression models as a surrogate for human faecal loading indicates that a significant proportion of the thermotolerant coliforms and faecal streptococci would have derived from human faeces.

The inclusion of eroded backfill and lack of a fence in the final logistic regression models for case study 3 (table 5.38) suggests that direct contamination routes
predominate. It is likely that the erosion of the backfill and surface water uphill interact as water inundates the area. In this case rainfall will act as a primary factor as it will aid both the washing in of contaminants into the backfill area and replenishment of the surface water uphill.

Case study 2 shown in section 5.3.2.3 also supports the theory of poor sanitary condition of the immediate source protection works and rapid recharge being primarily responsible for contamination events. In this case, the final logistic regression model does not contain any variables that relate to sources of faecal material and although no data were available for rainfall, this model indicates that direct ingress of contaminated water at the spring site was the primary cause of contamination.

Case study 1 shown in section 5.3.2.2 indicates that sources of faeces are more important in causing contamination. Latrines within 30m are included within the logistic regression models when analysing data from springs in both high density and low-medium density areas. Density of population is also included within two of the models (above 0 and 50 cfu/100ml or above) indicating that overall faecal loading is important. The lack of association with rainfall contradicts the findings of the other two case studies.

The poor sanitary condition of many of the protected springs indicates that if the quality of water is to be improved, greater attention should be given to preventing pathways into the source from developing. This was addressed through feedback and meetings with communities by the field staff who discussed how the development of such pathways could be prevented. In particular, attention was paid to the maintenance of fences, clearing and maintaining diversion ditches and protection of the grass cover over the backfilled area, although in some cases basic repairs to the protection infrastructure were also undertaken. Initiatives of this sort were undertaken in Mbale, Tororo and Masaka and were shown to yield reductions in thermotolerant coliforms (in the range of 1-2 logs), although data were not collected to evaluate long-term performance.
Contamination also resulted from poor designs used in the original protection works, which primarily relied on the use of a single retaining wall with large diameter hardcore placed behind. Water from spring ‘eyes’ was run through channels created in the backfill area and the whole backfilled area was then covered by plastic sheeting, murram and a grass cover planted. This design offers virtually no potential for attenuation as water flowed through the backfill area and the protection offered by the plastic sheeting, murram and grass cover was rapidly lost due to damage from overland flow (Howard et al., 1999; Howard et al., 2001a).

A small pilot project to re-protect springs in Kampala using an improved design proved that very considerable reductions in microbiological contamination are possible through effective sanitary completion at the source (Howard et al., 2001a). In this pilot activity, 5 springs were selected in high-density settlements and an improved design used. This used finer grained backfill media at the base of the spring (gravel with a nominal diameter of 25mm) and no channels to run the water to the outlet. This was done to maximise the flow paths of water entering the protection works in order to enhance the potential for attenuation.

The backfilled area was contained within wing-walls to ensure adequate flow from the outlets. The water-bearing layers were protected through the use of fine sand and clay overlays, which reduced the potential for direct ingress and offered potential for attenuation of any water seeping through the matrix. The whole backfilled area was covered with grass. The protection works were surrounded by a brick wall and lined diversion ditches. Live hedges were planted inside the wall with the aim to replace the wall with a natural protection. The lining of the diversion ditches was designed to maximise their life span, which was expected to be considerably longer than the previously used unlined ditches.

The springs showed significant (2 log and greater) reductions in thermotolerant coliform levels after re-protection. In addition to re-protection of the spring, training was provided to water source committees and community operators on maintaining the spring works. This included the development of tools discussed in section 7.1.1 and shown in Annex 4, which allowed for action-orientated monitoring by both the
committee and the operator.

Although the evidence from the analysis points to poor operation and maintenance as the principal cause of microbial contamination, studies of nitrate and chloride in case study 3, showed that there was widespread faecal contamination of the aquifer (Barrett et al., 1999; Barrett and Howard, 2002; Howard et al., 2002b). This was found particularly in higher-density areas, although the limited sanitation coverage suggests that this was not derived from pit latrines. Nonetheless, the development of on-site sanitation would in the longer-term be likely to represent a threat to protected springs in Kampala. It is unlikely that this would be greater than the current levels of contamination, but indicates that re-protection of springs should only be seen as an incremental step in improving water quality of sources used by the population. The further development of the piped network would remain the preferred long-term solution.

7.5.4 Household water

The results of testing the quality of water stored in households indicated that in many of the towns the median numbers of thermotolerant coliforms were relatively low, but that the range was considerable. It was also concluded that in Kampala in particular the quality of the water improved between the 3rd quarter in 1998 and the final quarter of 1999, indicating that hygiene education programmes had been successful in promoting improved water handling.

In the three towns in eastern Uganda there was limited evidence of improvement in water quality over time, although in Mbale median numbers of thermotolerant coliforms remained low for most of the study. The lack of improvement in household water quality in Soroti undermined the shift in water source use shown in section 6.3. The use of boreholes with no contamination suggests that in Soroti, household water was re-contaminated during collection and transport, which both Jensen et al. (2002) and WHO (1997) note regularly occurs.

It is also possible that thermotolerant coliforms found in household water were derived from biofilm in the storage container which were commonly clay pots, unlike
in other towns where plastic containers were used. The inside of these containers

tends to have many more imperfections and provides an environment that would
readily support the development of biofilm. The data collected did not allow this to be
investigated in more depth and this would be an area for future work.

The increasing number of samples from the Kampala that did not show the presence
on thermotolerant coliforms provides some evidence that surveillance programmes

can be used to promote good water handling. The improvements in household water
quality in Kampala were not evenly spread throughout the Divisions, which suggests
that improvements are incremental, take time to emerge and depend on the degree of
staff time committed to feedback of results.

As discussed in section 5.4, the analysis of data showed that there was an association
between using NW&SC and rainwater and lower levels of contamination. As noted in
section 5.4, however, some caution must be applied in projecting the findings of these
analyses because of the overall small data set included in the analysis. The association
with lower levels of contamination and water from NW&SC supplies, which showed
little contamination, suggests that households were able to maintain good water
quality up to the point of consumption. The containers used (plastic Jerrycans) would
have limited the potential for recontamination during transport and storage and this
would suggest that hygiene education programmes can be effective when
concentrating on the promotion of the use of good quality sources of water as well as
good water handling. The data from Soroti support the necessity of concentrating on
both these messages. These findings are supported by Jensen et al. (2002) that showed
that where contamination of water sources is low, hygiene education could be
effective in ensuring low levels of contamination in household water.

The difference between the proportion of households stating that they boiled water
prior to drinking in the water usage study and the numbers of samples provides
evidence for the need for ongoing hygiene education regarding water storage,
providing evidence of this. In Kampala, there appears to a reasonably close
correlation between reported boiling and the number of samples with no
thermotolerant coliforms in both Central and Rubaga. This indicates that the
promotion and uptake of safe water handling practices in these Divisions was good. In the other Divisions in Kampala, there is a wide disparity between reported boiling and household water quality. This is likely in part to be due to the lower socio-economic conditions in many Parishes in these Divisions where household water quality testing has been carried out, but also to less effective health education (Almedon et al, 1997).

The difference between stated boiling and quality of water in the home is an issue of concern as it suggests that although most households accept the need for boiling, a very significant proportion of households do not translate this into practice. Boiling of drinking water has in many ways become a socially desirable response for low-income families when questioned about household management of water but not something that is perceived as being essential.

The inclusion of household water testing is justified in surveillance programmes in order to address water quality from the source up to the point of consumption (WHO, 1997). Simply testing the sources of water may have provided only limited evidence of the overall state of water quality as consumed. As noted by Jensen et al. (2002) and Moe et al. (1991), testing of household and source water provides indications of the type of interventions required. The link between source type and household water quality identified in this study would warrant further investigation, to assess what levels of source contamination will outweigh any improvements in household water possible through health education.

7.5.5 Water quality parameters for microbial quality

The evidence from this study supports the continued use of indicator bacteria in surveillance of microbial water quality. In general, the indicator of preference remains E.coli because it can be more directly linked to faecal contamination (Ashbolt et al., 2001; OECD and WHO, 2001). Although as discussed in section 2.2.1, there remain concerns about the proportion of thermotolerant coliform from non-faecal sources, OECD and WHO (2001) conclude that these remain a viable surrogate for E.coli.

Although tests to directly detect E.coli have been developed (Bartram and Ballance, 1996), these are more expensive than tests for thermotolerant coliforms and there are
limited low-cost field testing kits. As discussed in section 7.2.1, surveillance programmes in developing countries benefit from the use of field kits and in particular provide greater potential for community involvement.

Although studies by Payment et al. (1991) in Canada identified disease incidence from consumption of water meeting guidelines for *E. coli*, there are no comparable studies in developing countries. In the cholera epidemic in Kampala, the erection of standpipes appeared to have been a contributing factor in controlling the spread of disease and this water met the current guidelines for thermotolerant coliforms. This is supported by the conclusions of Ince and Howard (1999) and Payment et al. (1991) about the benefit of meeting guidelines for *E. coli* in epidemic control.

As noted by Moe et al. (1991), other routes of diarrhoeal disease transmission are more important than consumption of water unless the water is heavily contaminated, a view supported by Cairncross (1990b). Given the evidence of the work reviewed in section 2.2 by Ashbolt et al. (2001), the use of other microbial indicators would be of value for water suppliers, but the costs involved would probably make this unrealistic to implement as part of health-based surveillance.

Within the study in Uganda, the other water quality indicators (chlorine residuals, pH and turbidity) were found to be useful in line with current recommendations (WHO, 1993; 1997). In particular the chlorine data was important in analysing microbial water quality management in piped supplies. The study also supports the views of Lloyd and Bartram (1991), Lloyd and Helmer (1991) and WHO (1997) of the importance of sanitary inspection when considering microbial contamination.

For point sources, case study 3 (section 5.3.2.4) for protected springs indicated that there was a much better relationship noted between faecal streptococci and sanitary risks, although thermotolerant coliforms were more commonly isolated. The more frequent isolation of thermotolerant coliforms may simply reflect the greater number of these organisms released into the environment from human faeces (Howard et al., 2002b; WHO, 1996).
A related study undertaken in Kampala showed a much stronger relationship between sorbitol-fermenting bifidobacteria (which are unique to human faeces) and faecal streptococci than with thermotolerant coliforms (Barrett et al., 2000b; Howard et al., 2002b). This suggests that faecal streptococci are more useful as a microbial indicator of relevance to health. A similar conclusion has been drawn for monitoring of microbial quality of recreational water (Bartram and Rees, 2000). However, although the studies for microbial contamination of protected springs suggest that faecal streptococci are better indicator bacteria, the data from testing of boreholes undertaken as part of case study 3 (section 5.3.1) were less conclusive.

Even if faecal streptococci are better indicators than thermotolerant coliforms, their use for surveillance programmes in developing countries remains unlikely as the length of incubation is much longer (48 hours). This may make use of battery operated kits more difficult as the load on the batteries would be much higher. In other respects, however, the analysis of faecal streptococci is relatively simple and uses the same techniques and incubation temperature as thermotolerant coliforms, implying limited need for changes in equipment. The potential use of faecal streptococci may be increased if their use is in smaller assessments of water sources to define causative factors for contamination, as discussed in chapter 8.

7.5.5.1 Sampling strategies

The sampling strategies for both the utility and the community-managed piped water supplies were based on the population served as outlined in the WHO Guidelines for Drinking-Water Quality (WHO, 1993). In the study in Uganda, sample numbers were based on estimates of actual use rather than populations residing in an area. Sample numbers therefore more accurately reflected the importance of piped supply.

Maul et al. (1990) and Haas and Heller (1990) suggest that it is more effective to base sampling on the distribution of bacteria within piped water supplies, using data from extensive assessments, as well as on the system characteristics. Suggested approaches rely on statistical models, primarily based on the Poisson and log-normal statistical distributions, which appear to reflect microbiological distribution most accurately (Maul et al., 1990; Haas and Heller, 1990).
Such approaches, however, remain difficult to apply at present because they involve complex statistical analysis and modelling of data that are rarely within the ambit of water suppliers and surveillance agencies. Furthermore, the available evidence suggests that the minimum number of samples required becomes rapidly very high and unrealistic for most routine monitoring programmes (Mark Sobsey 2002, personal communication).

7.5.5.2 Stratified sampling

The use of stratified sampling approaches is widely applied in monitoring piped water supplies as a means of recognising the influence of major infrastructure on water quality (WHO, 1997; Howard, 2002). The most commonly used form of stratified sampling is zoning of the system and examples of this approach have been applied previously in developing countries (Lloyd et al., 1991; WEDC and RCPEH, 1999). However, in most of the towns in Uganda, there was little point in trying to zone the water supply system. The majority of the NW&SC and Municipal Council operated supplies had only one service reservoir and few Ugandan towns had direct connections on the transmission main.

In Kampala, where zones could be defined, the surveillance programme did not base sampling on the supply zones. These were complex and showed many areas where adjacent streets would have fallen into different zones. It was felt that this would have made fieldwork unnecessarily complicated for field staff and may have had a counter-productive outcome as it could potentially have led to greater use of fixed sampling points, thus losing the random element. For the surveillance programme, it was therefore decided to use the zones when analysing data but not in designing sampling programmes. Work was, however, undertaken with NW&SC who adopted the zones as a basis for their subsequent sampling programmes, an approach more feasible given the available resources within the water supply sector.

The collection of samples throughout the month varied between towns. In Kampala where equipment was available in all Divisions, sampling from the different parts of the system was spread throughout the month, although in many cases it proved difficult to prevent field staff from concentrating sampling on particular days. In other
towns, sampling in a particular Division was typically clustered into particular weeks as the number of kits available (one per town) prevented more evenly spread sampling. Whilst this may not have been ideal, the purchase of greater numbers of kits was not possible and in any case would not have been cost-effective given the relatively low number of samples taken per month. A degree of compromise was necessary between what was desirable from a scientific perspective and what was feasible.

In the high ambient temperatures in Uganda, the time of day when samples were collected could also be expected to be important. Bailey and Thompson (1996) and Howard (2001) note that the temperature of water stored in service reservoirs during the day may lead to loss of free chlorine residual. In the study in Uganda, sampling was primarily undertaken during afternoons as this was felt to be the time at which the system was under greatest stress and when thermotolerant coliforms would be most likely to be isolated.

7.5.5.3 Point sources

The data from the study in Uganda highlight the value of well-designed studies in developing an understanding of the interaction between risk factors, climate and microbial quality for point sources. For instance in case study 1 for protected springs (section 5.3.2.2) there were many confounding factors that were noted in relation to the data analysis. Case study 2 (section 5.3.2.3) and case study 3 (section 5.2.3.4) were more rigorously designed and the analysis was less influenced by confounding factors, thus strengthening the conclusions that could be drawn.

The study in Uganda therefore strongly indicates that for small systems, there are two requirements:
1. well-designed and executed studies of a sample of supplies that can be visited regularly; and,
2. lower intensity monitoring based on a rolling programme.

The use of studies is primarily designed to provide information to inform strategy and policy for the improvement in water quality. The data can be extrapolated more
broadly and feed into design and construction criteria as well as training needs for communities. These can be then be utilised by surveillance staff in discussion with communities about how their water source may be improved. The role of the routine monitoring is to provide information on overall risks from urban water supply and to provide evidence to individual communities regarding the quality of water they consume and the risks that this poses to their health (Bartram, 1996; 1999).

7.5.5.4 Household water

The sampling strategy for household water was primarily designed to collect data on quality of water stored in the home within low-income areas through an ongoing programme rather than in relation to specific interventions. This was a deliberate decision designed to assess broad trends and practices within low-income households as a check on whether the water quality within homes showed evidence of faecal contamination in the same manner as the studies performed on piped water.

The sampling programme has some weaknesses, as matching with source water proved difficult and such data would have provided better evidence of the importance of re-contamination. With the development of the sanitary inspection form, these data proved easier to collect and thus allowed some, albeit limited, analysis.

As noted in section 6.3, multiple source use is common within low-income households and the same containers were used irrespective of the source. Therefore, some caution must be expressed regarding the strength of conclusions drawn about the relative influence of source water and re-contamination. For instance, although the water sampled on a particular day may have come from a good quality source, water in containers may have retained residual contamination from the prior use of a contaminated source. Furthermore, given multiple source use noted in section 6.3, household water may be of good quality at the time of sampling because a good quality source was used, but on a repeat visit the quality of water may have deteriorated because a low quality source was subsequently used. Jensen et al. (2002) note the importance of source water quality on the quality of water found in household containers.
The approach adopted should primarily be viewed in the context of evaluating the reliability of self-reported behaviour regarding household water. As so many poor households claim to boil water prior to consumption, no thermotolerant coliforms would be expected in drinking water irrespective of source water. The quality of household water in such cases would also be expected to be independent of any re-contamination during transport and only re-contamination post-boiling would be of interest. Such information would be difficult to obtain outside of specific studies, probably requiring extensive effort and qualitative research methods. The data shown in section 6.3 indicate that valid conclusions can be drawn based on evaluating household water quality and reported boiling behaviour.

On the basis of the work in Uganda, it appears justifiable to include random testing of household water, even if this is only able to provide an indication of the trends in household water quality. If this is combined with feedback to communities, some progress can be made in improving quality of water stored within the home. The use of household water quality assessments linked to specific hygiene education interventions is also likely to be of value and represents an area where further work is required.

7.5.6 Sanitary inspections

The programme of study in Uganda demonstrates the value of sanitary inspection in water quality monitoring programmes and in assessing overall operation and maintenance. However, experience showed that forms taken from WHO (1997) needed to be refined to take account of local conditions and in the case of piped supplies, changes were required in the overall approach adopted.

7.5.6.1 Piped supplies

The research in Uganda highlighted some methodological problems with undertaking sanitary inspections on urban piped water systems. As most sanitary inspections are based on observation of the supply, there are inherent problems with carrying them out when the infrastructure is less accessible for inspection. Leaks within deep-laid pipes are often difficult to detect through observation and given usual flow rates, contamination may have occurred many metres if not kilometres from the sample site.
To develop a full-scale risk assessment of an urban piped network requires collection and analysis of a range of data such as leakage rates, land-use, population density, biofilm formation potential, chlorine demand, pipe age and material and pressure data. This is an area of further work as discussed in Chapter 8. The development of detailed risk assessment approaches would logically be of greatest value for water suppliers. It is unlikely that surveillance bodies would be required to collect data for such assessments, although they would need to review the data generated (Howard et al., 2002c).

The use of simple visual assessment and community interview provided useful information regarding the major risks to the systems and the domain of principal risks — whether supply faults or localised risks. Although the development of more detailed risk assessment tools is justified, it is unlikely that on-site sanitary inspection components will be removed. The use of the simple tools that allow some estimation of likelihood of risk factors employed in the approach in this study remain justifiable, especially when undertaken by a surveillance agency (Lloyd et al., 1991). For water suppliers, the development of risk assessment approaches is also likely to include components of sanitary inspection as used in this study (Howard et al., 2002c).

In Uganda limited data were collected on the direct risks found at service reservoirs, largely because of the difficulties in gaining access to utility installations. Attempts were made to ensure that NW&SC and the Municipal water suppliers undertook regular inspection and this proved to be effective. In subsequent work in Ghana, the regular inspection of service reservoirs became a standard approach and the utility also found the use of the simple sanitary inspection forms developed in Uganda helpful in their regular monitoring and management practices (Howard, 2002).

In Uganda undertaking sanitary inspections for a whole Parish provided an adequate overview of the state of the system. This was not perfect, but provided sufficiently robust data for analysis of sanitary inspection and water quality data together, as shown in section 5.2.4 and to allow evaluation of overall sanitary risks. This approach has also been found to be effective in previous work (WEDC and RCPEH, 1999).
In the community-managed supplies, the sanitary inspection forms proved effective. The data generated were sufficiently robust for analysis of sanitary inspection and water quality data together, as shown in section 5.2.3 and to allow evaluation of overall sanitary risks.

7.5.6.2 Point sources

The sanitary inspection forms for boreholes and protected springs proved to be effective in identifying major sanitary risks. The form for boreholes does not include a question on the presence of an uncapped well close to the borehole, which has been shown in other countries to be an important route for contamination (Rojas et al., 1995). In the towns covered by the surveillance project in Uganda where boreholes were found, there were no uncapped dug wells within a reasonable distance (100 metres) and therefore this question was deemed redundant.

The sanitary inspection form used for protected springs proved to be a valuable tool that allowed major causes of contamination to be identified and operation and maintenance performance evaluated. This form was significantly modified from those in WHO (1997) to provide more specific information on pathways and contributing factors.

The overall relationship between sanitary risk score and level of contamination for protected springs provides good evidence of the effectiveness of the approach taken. However, although some individual factors in inspection of both boreholes and protected springs appeared not to be statistically significant in relation to contamination, in all cases their inclusion was justified in developing an overall assessment of sanitary status and operation and maintenance.

The analysis of the sanitary inspection and water quality data showed that not all risk factors showed a statistically significant association with contamination when they were present. However, all the factors included were noted as important in describing overall sanitary status (Bartram, 1996; Lloyd and Bartram, 1991).
Despite the clear indication of the predominant influence of particular risk factors on microbial contamination, this would not support a differential weighting of risk scores to be applied in all settings, which agrees with the conclusion of Bartram (1996). This is shown by the differences found in the statistical models developed for protected springs in the case studies shown in sections 5.3.2.2 to 5.3.2.4. It can be concluded that identifying the importance of individual risk factors should be done through analysis of data using equal weightings rather than applying differential weighting in the data collection. This will ensure that local factors of importance can be identified in each setting and lead to better informed decisions for improvement strategies. By undertaking such analysis, monitoring data can be transformed into management information that is noted by Ongley (1998) and Timmerman and Mulder (1999) as being essential.

7.5.6.3 Household water

The development of sanitary inspection forms for household water storage containers was only carried out relatively late in the programme, although their use was widespread in early 2000. The development of these forms was hampered by the limited access to households by the author and the national team directing the surveillance programme and the wide variation in types of container used both within and more particularly between towns, which made standardisation more difficult. The final forms developed did prove to be effective in providing some indication of likely factors leading to contamination, although they did not capture one of the major likely causes of contamination problems relating to the container material.

Sanitary inspection forms for household water almost certainly need to be developed for each type of container and therefore lose some of their comparative value. There are also concerns that because contamination of household water may occur through many different ways and at different times during the collection, transport and storage process, any inspection forms developed would be unlikely to be as standardised as those for sources of water and very time-consuming to fill in. Whilst the forms developed in Uganda provide a reasonable attempt at developing sanitary inspection for household water, it is recognised that this is an area where further work is required.
7.5.7 Assessing the effectiveness of analysing system failures

For the urban piped water systems, the statistical analysis provided valuable insights into the water quality management and in particular proved useful in failure analysis (Tillett et al., 2001). For these systems the inclusion of chlorine residuals and sanitary inspection data was essential to gain a clear idea of why contamination events occurred. The analysis using contingency tables and logistic regressions was shown to be important in understanding the interactions between sanitary risks, chlorine and microbial quality. Therefore the use of complex models can be seen to be important when analysing performance of urban piped water systems (Tillett et al., 2001). The analysis would have been strengthened if quantitative leakage data had been available, but as these were not collected by the suppliers this was impossible.

The disadvantage of the approach used is that no analysis could be directly made of the importance of biofilm on the presence of thermotolerant coliforms. Some species that are thermotolerant could have been derived from biofilm (WHO, 1996a). Various studies have shown that a number of factors may influence biofilm formation including the biological stability of the water, temperature and pipe material (van der Kooij, 1993; Bailey and Thompson, 1996; Yeh et al., 1999; LeChevalier, 1999; Muyima and Ngackani, 1998).

Routine monitoring and assessment of biofilm formation relies on calculations of assimilable organic carbon (AOC) and heterotrophic plate counts (van der Kooij et al., 1999; Klein and Forster, 1999). LeChevalier (1999) notes that the routine calculation of AOC is difficult and costly and would be beyond the means of most utilities in the USA. Furthermore, the lack of evidence of public health risks derived from biofilm suggests that whilst it is important to know if most thermotolerant coliform are derived from biofilm rather than ingress, there is no strong public health reason for monitoring biofilm (LeChevalier, 1999; Payment and Robertson, 2002).

Various workers have suggested that because the application of a free chlorine residual within the distribution system is a control measure of biofilm in both temperate and tropical environments, monitoring can be restricted to chlorine residual and coliforms (Bailey and Thompson, 1996; Haas, 1999; LeChevalier 1999; Muyima
and Ngackani, 1998; Trussel, 1999). Within the Uganda study, it was concluded that the use of logistic regression models including chlorine residual would account for some, if not all, biofilm influence on thermotolerant coliform presence.

The analysis of data for point supplies provides good evidence that the analysis of interactions between individual risk factors and levels of microbial contamination is of great value in understanding relationships between different risk factors. This is of particular importance when identifying how water quality may be improved in order to ensure that the most effective interventions are prioritised. This is illustrated in Uganda by the noted importance of pathway factors in causing contamination rather than obvious hazard factors in sections 5.3.2 for protected springs. This allowed improved designs for the protected springs to be developed, which would not have been possible had the principal cause of contamination been related to sub-surface leaching from hazards in the environment.

Lloyd and Bartram (1991) concluded that the combination of sanitary risk score and contamination is a useful means of identifying priorities for interventions. In the studies on protected springs in Uganda this type of analysis provided less useful information upon which to base improvement strategies. Although it could have been used to identify which protected springs were most in need of rehabilitation, it would not have provided information regarding which types of intervention (improvement of protection works or removal of pit latrines) would yield the greatest benefits.

Although the statistical analysis of the data in contingency tables and logistic regression models was relatively complex, the strength of the conclusions that can be drawn shows the value of this approach. Although some of the same conclusions could be drawn on the basis of variation in frequencies reported for each factor when a water quality target was met and when it was exceeded, this provides less certainty than the statistical analysis. In particular the development of the logistic regression models provides a means by which data analysis can provide a simplified overview of the major factors of importance in water quality deterioration.
7.6 Availability and access to water supplies

7.6.1 Access to water supplies from the inventory data

The results in section 6.2 show that there is a significant variation in the numbers of sources available for households without their own connection. The analysis in section 6.2.1 shows that there were limited relationships between the number of sources available and population and socio-economic status. Although significant correlations were found for the full data set with population this only held true for Kampala and Kabale. Likewise, the significant correlations with socio-economic status were only valid for Kampala and Masaka.

This analysis suggests that the variation in numbers of sources is due to a variety of factors, many of which are likely to be locally important. Such factors may include previous initiatives to make supplies available to the population that lacks access to a household connection. For instance, the relationship in Masaka with socio-economic level is likely to have been influenced by a large number of public taps established in a project in the late 1990s funded by the World Bank.

It is also possible that the number of households with a connection to the piped supply influenced the number of public sources, as where connection rates are high the demand for public sources may be limited. For instance, Entebbe and Mbale had considerable numbers of civil servants who were provided with housing and a connection to the water supply. Although the practice in the towns supplied by NW&SC during the period of study required significant capital outlay for a household connection, this has not always been the practice.

Howard (2001) and Kayaga (1997) note that in Uganda it was the capital outlay for acquiring a connection rather than recurrent costs that restricted access to a household connection. Therefore, it can be hypothesised that households who gained a connection under previous arrangements would find it easier to sustain these connections under the new system of water pricing based on cost-recovery than for unconnected households to obtain a new connection. This may explain why Entebbe and Mbale had so few ‘public’ sources.
Piped water sources are the most common form of water supply available in the majority of towns, with only Soroti, Masaka and Mukono having more sources of other types. In the case of Mukono this was because of the lack of a town piped water supply, whereas in Soroti and Masaka the reasons are less clear. The difference in Soroti between piped and point sources was very small. Discussions with the water department indicated that there were relatively few household connections to the piped supply and they reported frequent problems in operating the supply. It is therefore not surprising that non-piped sources predominated. In Masaka, the difference was significant and was more surprising given that the data collected suggest that this was generally a well-run supply. It is likely that availability of unprotected sources was a result of poor coverage of the piped network in the more peripheral Parishes in the town, where secondary and tertiary infrastructure was very limited.

The data suggest that ‘on-selling’ by neighbours was an attractive option for poor households because these facilities may be far closer to the home than the public facilities and a cost that is little different. This reflects wider experience within urban areas of developing countries both with regard to use of ‘on-sellers’ and pricing of water from public taps (Morris and Parry-Jones, 1999; Onek, 1997; Rabemanamobla, 1997; Tatietsé and Rodriguez, 2001; Thema, 1997). Only in Masaka do public taps from NW&SC supplies outnumber on-sellers. The inventory data for the town shows that this was a result of a specific project in Nyendo Parish to provide public taps. This was a relatively recent initiative and it would be interesting to repeat an inventory after 5 years to see whether provision through public taps was still more common than on-selling. The provision of water to a compound by landlords was restricted largely to Soroti and Jinja and it is likely that this developed because of renting practices.

It is probable that the number of piped water sources were under-estimated by the inventories as on-selling of piped water was common. Given the reluctance of some ‘on-sellers’ to admit to the practice, either because of concerns about potential punitive action or because it was limited to only a small group of neighbours, it is
likely that there were more piped sources than recorded by the inventories. The water usage study data in section 6.3 show that more households use piped water sources than would be predicted from the inventory. The under-estimation of 'on-selling' indicates that there are limitations in the inventory methodology, although there is no obvious way in which this could be overcome. The reliance on connection data would not, for instance, be a reliable guide. These findings give greater support to the need for water usage studies to be undertaken to gain a more reliable guide to usage, although as noted by Howard et al. (2002a) these require inventory data in order to be able define the objectives and study population.

In terms of the monitoring programme, the nature of piped water availability emphasised the need for water samples to be taken from private connections rather than public taps. This also had important implications for sanitary inspections and the use of the data in developing intervention strategies, as the local risk component had to focus primarily on household rather than community responsibility.

The existence of so many point sources in most of the towns appears to have resulted from initiatives to improve water supplies during the 1980s. This included rehabilitation of many point sources and the provision of public taps, although the latter was seen to fail fairly rapidly as cost-recovery was pursued. It is interesting to note that in Jinja there were no protected point sources. This may reflect the fact that the piped water supply was kept functioning during the upheavals in Uganda during the 1970s and 1980s as well as the limited availability of naturally occurring alternatives.

The rehabilitation of protected springs and to a far lesser extent, boreholes, continued into the 1990s. The data from inventories in a number of towns, showed that rehabilitation of point sources was linked to election campaigning by local politicians. The ongoing actions can be seen to be reflecting the demands of local populations for improved water supplies that they can manage and which have limited financial costs. Howard et al. (2001a) note that there was demand for rehabilitation of protected springs in low-income communities in Kampala during the period of study. As noted by Ahmed and Hossain (1997), Gelinas et al. (1997) and Rojas et al. (1995), the
provision of protected point sources is relatively common in urban areas of developing countries, suggesting that improvement in such sources is likely to be required in many situations.

Protected springs are found more commonly in urban areas than boreholes, which are found mainly in the towns in the East of Uganda and in Mbarara and Kabale. This reflects the hydrological and topographical environments that are conducive to spring formation. Their continued use appears to have been linked to the limited maintenance required to ensure that water continued to flow. The greater number of boreholes no longer functioning points to the difficulties in maintaining such supplies, a problem noted by other workers (Taylor, 1993).

7.6.1.1 Inventory forms

Inventories of water supplies are recommended in most texts on surveillance as the essential first stage in the development of a surveillance programme (Lloyd and Bartram, 19991; Lloyd and Helmer, 1991; WHO, 1997). Despite the weaknesses noted above, the study in Uganda supports the need for inventories at the start of the programme. Inventory data proved invaluable for subsequent planning of activities and ensured that the field staff had a clear idea of the nature of water supply in their areas of operation. The inventory provided the only means of recording the available sources of water for poor households and was essential in developing the zoning categories used and targeting the water quality monitoring on the most important water sources and vulnerable areas.

The wide range of data collected on each source during each inventory was found to be particularly important. In the case of cost of water at the point of purchase and continuity in supply, the data from the inventories was important as demonstrated in section 6.4 and 6.5. The inventories also provided an opportunity to collect information regarding the age of supply, rehabilitation work and maintenance activities undertaken, which were useful in developing an understanding of how low-income communities managed domestic water.

The collection of the data on available sources in low-income areas would have been
impossible without undertaking field assessments. Desk-based estimates would have failed to capture the full range of public sources (public taps and protected point sources in particular) and would have little chance of estimating the importance of 'on-selling'.

A particularly important output from the work in Uganda is that model inventory forms were made available for use in other surveillance programmes (Howard, 2002). It should be noted that these forms are the first models to be made available in the literature and should provide other surveillance programmes with tools to initiate better data collection.

7.6.2 Connection reviews

The experience from Uganda showed that there were difficulties in undertaking connection reviews. The NW&SC connection data did not differentiate between households with a single tap and those with multiple taps within the home. Such data would have been of interest in relation to assessments of access broken down by levels of service. Although data were kept on the diameter of the pipe supplying the home, discussions with NW&SC staff indicated that this could not be taken as a reliable surrogate measure of service level. Furthermore, the difficulties in relating the connection data to Parish population data made accurate estimates of on-plot connections difficult. In a number of cases (notably institutional and government connections) the data required significant manipulation and assumptions to be made as noted in section 3.4.2. The assumptions made may not be valid and thus led to significant error in the estimates.

In several of the NW&SC supplies and the Municipal supplies connection data were not available and therefore reviews were not possible in these towns. The lack of data of connections in Municipal supplies in particular appeared to be cause of poor cost-recovery. Although the surveillance programme could have collected connection data in Municipal run supplies, it was not believed to be essential given the evidence that overall connection rates were low. There is clearly a need to improve the collection of data on service levels in all utility piped supplies by both NW&SC and Municipal councils where these operate the supplies. The principal recommendation from the
Uganda study is that surveillance programmes should advocate that detailed connection data are collected by water suppliers. Such data should be made available to the surveillance agency (Lloyd et al. 1991).

7.7 Water usage

The data on water usage patterns in Uganda provided information regarding the importance of different source types used by low-income households and was important given the likely under-estimation of availability of piped water sources through 'on-selling' noted in section 7.3.2. The water usage data allowed zoning methodology to be refined to reflect user practice. The water usage studies ensured that user experience in relation to indicators of supply adequacy, such as water quality, discontinuity and cost could also be included within the surveillance programme (Howard et al., 2002a). This was of benefit because, as noted in section 6.5.3 for discontinuity, the data from water usage studies indicated that interruption to piped supply was found at a rate that exceeded that recorded through sanitary inspection in both Kampala and Soroti.

User perceptions of the importance of different water sources and reasons for selecting water sources noted in section 6.3, allowed the surveillance programme to identify the demands of communities for water supply improvements. This was used in providing evidence for those interventions with the greatest potential for sustained uptake. This is particularly important, as many of the previous approaches to water supply improvements in urban areas of Uganda, notably public taps, failed to be sustained beyond short-term interventions (Howard, 2001).

In Kampala, the type of water used as a first choice source largely reflects availability as determined by the inventory. However, the overall use of protected springs suggests that they are as important to low-income households as taps and therefore both protected springs and taps required equal consideration within the surveillance programme. This was further emphasised by the lack of evidence of particular water sources being used for drinking.

In Soroti, the use of point sources appears far more common than the use of taps. Both
the level of use of boreholes and protected springs in the town is much higher than predicted from the inventory data. The distinct differentiation in the use of water collected from boreholes places further emphasis on the need to monitor the quality of borehole water. Anecdotal evidence indicated that this ‘rationality’ in use was introduced by staff working on the surveillance programme who based health education programmes on the information collected through routine monitoring. This showed that the piped water and protected spring water often showed microbial contamination whilst boreholes rarely showed microbial contamination. Such rationality in the use of water from different sources is noted as occurring in low-income communities in both urban and rural areas of developing countries (Almedom and Odhiambo, 1994; Madanat and Humplinck, 1993). The overall low use of taps in Soroti suggests that fewer samples needed to be taken from the piped network.

In Masaka, the numbers of households using of taps was greater than would be predicted by the inventory and there was lower use of protected springs. Thus much greater weight was given to monitoring of piped water. Although unprotected springs were commonly used, this has little implication for surveillance, as they were not sampled because it was felt that no useful management information would be gained, as the conclusions on improvement were apparent without the need for water quality data. This is supported by the view of Bartram (1996), Ongley (1998) and Timmerman and Mulder (1999) that monitoring programmes must meet management needs for information.

The common use of rainwater as a supplemental source of water in Kampala and Masaka suggests that this was important to consider, although as most households did not use an improved method of guttering and tank, it would have been difficult to perform a sanitary inspection. The collection of rainwater would have implications for interpreting-the results of testing of water stored within the home as seasonal variations in household water quality could be influenced by the collection of rainwater. The data shown in section 5.4 do not indicate any obvious seasonal variation in microbial quality and it is unlikely that there was a significant influence. The low level of use of rainwater in Soroti implies that this had little significance for surveillance in this town.
Vendors in Soroti and Kampala typically used protected springs and boreholes as sources, as payment was not required at these sources. The significant use of vendors in Soroti, and to a lesser extent in Kampala, further indicated that protected springs and boreholes require regular testing and inspection. By contrast, the absence of vendors in Masaka further points to the lower importance of protected springs and thus sampling and inspection could be primarily limited to times of known elevated risk.

The difference between use and availability of water sources has been noted, as have variations within each urban area. Howard et al. (2002a) conclude that the role of water usage studies is to help the surveillance programme to refine the activities undertaken in order to make them more focused on those areas of greatest need and to reflect the importance of different sources. Howard (2002) notes that the limited financial resources available to support surveillance in developing countries imply that decisions must be made regarding priorities for surveillance based on maximising the benefit for the greatest number of people.

Although water usage data provided a more reliable basis for establishing the importance of different water sources for the surveillance programme, they do not replace the need for inventories of water sources. Howard et al. (2002a) conclude that water usage studies are warranted where the inventory identifies that more than one water source type is available, for which there is some evidence of use, even if this is only anecdotal. This indicates that such studies will usually be required some time after the initiation of surveillance activities.

This study has demonstrated the value of water usage studies in surveillance programmes and it can be concluded that these are important components of a water supply surveillance programme. Important outputs of the Uganda study were tools available for water usage studies and detailed guidance on sampling strategies to be followed, which will assist in other surveillance programmes in implementing such studies (Howard, 2002).
7.7.1 Understanding usage behaviour

The results of the water usage studies show that selection of water sources by low-income households is a complex process, reflecting both household perceptions and supply performance (Almedom and Odhiambo, 1994; Howard et al., 2002a; Madanat and Humplinck, 1993). The greater use of taps in both Kampala and Masaka compared to Soroti (shown in section 6.3) reflects the greater reliability and higher quality service provided by NW&SC in comparison to the Municipal Council supply. In Masaka the predominant use of piped water was concentrated in Nyendo Parish and is likely to have resulted from a recent initiative to establish greater numbers of public taps. In the second Parish (Ssenyange) water use patterns were similar to Kampala with greater emphasis on protected springs and dug wells.

The analysis of water usage data in section 6.3 indicates a significant difference in the proportion of households using piped water as a first choice source between Kampala and Masaka. The sanitary inspection data suggest that the Kampala supply was less prone to discontinuity than the Masaka supply. There were, however, proportionally more public taps in Masaka (as shown in section 6.2) and the average cost of water purchased from taps in Masaka was half that in Kampala. It is possible that the lower cost of water in Masaka led to increased usage, but this is difficult to support.

The evidence on reasons for source selection in Kampala shown in section 6.3.5 indicates that cost was given by only 40% of users of protected springs as a first or second source. It is more likely that in Kampala the abundance of protected springs meant that these were probably closer to households than those found in Masaka, which would be supported by the high proportion of households providing distance as a reason for source selection. The water usage data for Kampala suggests that protected springs and taps are both viewed as being adequate water supplies by low-income populations as they are ‘protected’. This would explain the relatively low use of unprotected sources in the city. The equal value given to both protected springs and taps reflects the fact that many low-income households in Kampala are migrants from rural areas, familiar with protected springs as a water supply.

The limited use of vendors found in the water usage studies is interesting as this is at
odds with studies undertaken in other urban areas in Africa (Cairncross and Kinnear, 1992; WELL, 1998; Whittington et al., 1991). This is likely to result from the wide availability of alternative sources in all towns. Howard (2001) notes that data from a pilot water usage study in Kampala showed that there was greater use of vendors. When reviewing the socio-economic data for the Parishes where the pilot study was undertaken, vendor usage was higher in low-medium income Parishes. The greater use of rainwater in Kampala and Masaka than in Soroti appears to reflect climatic patterns. Kampala and Masaka are both on Lake Victoria and receive more frequent rainfall than Soroti, which has a more pronounced seasonal variation in rainfall.

The understanding of the reasons for using particular source types both as first and second choice sources of water provides useful information regarding policy and hygiene education interventions. In the policy area, the importance of distance provides a clear indication of key considerations to take into account when planning water supply improvements. The importance of distance suggests that new water sources must be closer than alternatives to encourage use or for significant hygiene education to promote particular sources for drinking water. The importance of quality in both Kampala and more particularly Soroti as a reason for source selection does, however, suggest that some gains were made through promotion activities focusing on safe water source selection. The value placed on the quality of the supply provided further support to the development of hygiene education programmes in Uganda. Briscoe et al. (1981) note that this was effective in Bangladesh.

7.8 Cost

The data on costs of water from Uganda suggests that poor households using public taps or purchasing from their neighbours typically paid far more than households with a connection to the piped supply. Numerous other workers have found similar findings in urban areas of developing countries (Briscoe, 1996; Cairncross, 1990; Cairncross and Kinnear, 1991; Franceys, 1997; Hardoy and Satterthwaite, 1989; Stephens, 1995a). The potential health consequences of this have also been highlighted in previous work (Cairncross and Kinnear, 1992; Lewin et al., 1996; Lloyd et al., 1991). The analysis in Section 6.4 shows that the average cost of piped water paid by households lacking their own connection was almost 75% higher than
the price paid by the largest commercial consumers.

The data on costs of water from Uganda (shown in section 6.4.1) show that taps were the principal source where payment was required. The variation in charging practices between the towns is noticeable and the requirement to purchase water from public taps showed a clear differentiation by water supply administration as shown in section 6.4.1. Both the requirement to pay and the costs are typically higher in NW&SC supplies.

Within the different modes of provision of piped water, water provided by landlords to a compound with several families are those where payment is least often required. Where payment was required, the data also indicate that taps provided by landlords to a compound of several families results in the lowest cost of water. The costs of the purchasing water from such sources in Jinja and Soroti are probably internalised within rents paid to the landlord. The data are, however, somewhat limited and only the data from Jinja is comparable to other towns. Public taps, by contrast, usually charge for water presumably because alternatives for internalising costs in other payments are restricted.

The data in section 6.4.1 shows that private 'on-selling' was the most common form of piped water available for households lacking a connection. The average cost of this water was three times the charge levied by the National Water and Sewerage Corporation for water to household connections. This additional charge, which represent the 'profit' margin for the local supplier is significant and may underpin household use of water by the 'on-seller' (Morris and Parry-Jones, 1999).

The small difference in costs of water between 'on-sellers' and public taps illustrates that the social provision of water through public taps does not necessarily provide significant reductions in cost of water to low-income households (Onek, 1997; Rabemanamobla, 1997; Therna, 1997). In Kampala, the price from public taps shows no significant difference to that from on-sellers, despite the significantly lower charge per unit volume levied by NW&SC.
The reasons for the excess price at public taps can be linked to several factors. There was clearly a thriving local market for water in urban Uganda. The cost of water at the point of collection therefore reflected local market forces rather than social provision, as shown by the standardisation in price across public and private selling. The provision of water through public taps where charges are levied entails additional administration costs for the community who own the tap, as an operator must be retained. Furthermore, many public taps are erected with the expressed purpose to raise funds for other activities, such as health services, and communities are encouraged by donors and NGOs to follow this route.

During the study, NW&SC had a policy of levying minimum charges on users of all facilities, which in the case of public taps was equivalent to 75m³ per month (Howard, 2001). This raises the threshold for cost of water to users in order to cover static costs of water. It is not clear why this was carried out as all taps were metered and therefore, in principle, NW&SC charges were based on actual use. Mutabazi (2001) notes that minimum charges affected lower-density areas disproportionately, as the numbers of users was often insufficient to guarantee that the minimum charge was recovered.

In discussions between the author and one local water management group that operated several taps in Banda Parish, Kampala, it was noted that this problem was overcome by subsidising the cost at taps with low usage with income from more heavily used taps. It was noted that this led to increased waiting times at more heavily used taps. There was an ongoing advocacy campaign by the Surveillance team, NGOs and local Councils to have these charges dropped and more recent developments have seen the removal of these charges (Sam Kayaga 2001, personal communication).

The data from the water usage studies show limited changes in price of water in Kampala in the two years from when the inventory was carried out. This was despite the significant depreciation in the value the Uganda Shilling (from USH1000:US$1 to USH1500:US$1) and rising costs of other consumable durables for which it may be presumed that the profit margin of on-sellers is in part designed to provide capital to purchase. In the case of public taps, as profit was used either to pay operators or to
provide funds for other activities, it again appears somewhat surprising that broader economic changes are not reflected in increasing prices. The lack of change in tariff charged by NW&SC may have influenced this, although there is little evidence to support this.

There may be several reasons for the lack of change in cost. The most convincing explanation is that the cost per Jerry can was the local market price, which was accepted by users and sellers as being fair, although there is no direct evidence to support this. The significant level of multiple source use among households using a tap as first source in Kampala suggests that when households found the cost unaffordable, the response was to use an alternative source.

This is supported by conclusions by Howard et al. (1999) with regard to use of acceptable alternative sources during periods of hardship with return to the preferred source when household finances permit. This is reflected by the higher reporting of cost as a reason for selecting a protected springs as a second choice water source when the first choice supply was a tap in the water usage studies in Kampala and Masaka. The data from the study in Uganda suggests that there is elasticity in source selection but not in cost of water.

The study in Uganda confirms the importance of cost as an indicator for surveillance programmes, but indicates that this should be based on the costs of water when purchased rather than relying on published tariffs. The data on cost of water and source use indicate that poor households are expected to pay for more piped water and as a result use multiple sources of water, which increases the risk of disease. Reducing the costs of piped water for poor households may be difficult to achieve unless the mode of delivery is changed. The promotion of shared taps may offer one solution as noted by Sansom et al. (2000), although there is at present limited experience to evaluate.

**7.8.1 Cost as a barrier to uptake of services at higher levels**

The data shown in section 6.2.2 show that the proportion of households with a connection to the piped supply was low in Kampala. The evidence from Uganda
suggested that it was the cost of connection that presents a barrier to uptake of service (Howard, 2001; Kayaga, 1997). During the period of study, a household connection to a NW&SC supply required a connection fee of USH 125,000.00 (approximately US$85), a sum that covers the installation of the meter. This is essentially a ‘joining’ fee. In addition, the household wishing to connect is also required to pay for the materials and labour to install the customer main running from the supply main and to ensure that this is done properly to limit the potential for leakage. Thus average total connection costs may be around USH 600,000/00 (in the region of US$ 400).

In a study of households using off-site water sources in Kampala, Kayaga (1997) reported that the most important perceived barrier was the cost of purchasing materials. Some low-income communities and households suggest that payment of connection fees by instalment or access to credit to allow purchase of materials and labour would make such costs more tenable.

The cost of acquiring a connection may not be the only influencing factor and the household must consider other competing demands for capital investment. In Uganda, the 1995 Demographic Health Survey showed that whilst only 12.7% of the urban population had water piped into their home, 67.2% of households owned a radio, 24.5% owned a bicycle and 17.3% owned a television (Government of Uganda and Macro International, 1996). This suggests that the perceived value of a water supply is often set against other goods and does not necessarily come high on the list of household capital investment. Furthermore, the increase in service level may be viewed negatively by some poor households where this leads to increases in rent or because it diverts money away from the preferred investment in the home rural area (Andreasen, 1996; Hardoy and Satterthwaite, 1989).

In addition to the capital investment costs associated with obtaining a water supply, the method of billing may also influence the decision to acquire a connection. Howard et al. (1999) note that poor households may find difficulties in paying for water use from a household connection as the system of tariffs and billing is relatively inflexible. By contrast, where water is purchased from a vendor or neighbour, payment is made directly on collection and should there be a short-term financial
difficulty, purchase of the water may be stopped immediately provided a socially acceptable alternative is available. The data on multiple source use (shown section 6.3.2) support this conclusion and as noted above reflect elasticity in source selection behaviour.

Subramanian et al. (1997) show that elsewhere in Africa subsidising connection can be effective. They quote an example from the Cote d'Ivoire where the utility provided 75% of their connections with no direct connection fee and as a result maintained a connection rate of 70% in urban areas with connections growing at 5-6% per annum. Howard (2001) questions whether it is necessary to provide subsidies on connections, as the urban poor primarily operate within the monetary economy and are both willing and able to pay for services and goods. Several workers (Andreasen, 1996; Cairncross, 1990a; Hardoy and Satterthwaite, 1989; Satterthwaite, 1997), note that a key problem for the poor is the lack of access to credit on favourable terms for capital-intensive investments such as connection to the piped water supply. Therefore the development of approaches that increase the access of the urban poor to credit to support major household capital expenditure may be effective in increasing access (Hardoy and Satterthwaite, 1989).

The study in Uganda indicates that understanding these barriers to access to higher service levels is important and these issues were discussed in stakeholder meetings. This led to an increasing recognition of the need to re-evaluate the pricing structure and development of systems providing greater flexibility in service provision.

The achievement of more flexible systems is a long-term goal, but the importance of the surveillance data in promoting actions was seen to be significant by both the health and water supply sectors. Although it can be concluded that surveillance programmes should address the issue of lack of uptake of connections, this does not imply that specific details need to be gathered regarding actual pricing policy by the surveillance agency. Such assessment should be primarily within the remit of the water supplier as they develop strategies to deliver better services to low-income communities (Sansom et al. 2000). The role of surveillance should be to identify where problems exist and advocate for their resolution by the water supply sector.
7.9 Continuity

The data collected in Uganda demonstrate significant variation in continuity of supply. The inventory data suggests that almost 20% of all water sources experienced some discontinuity in supply. This was usually an occasional event, although 10% of sources experience daily interruption, these primarily being taps found in Kabale and Mbale. In the case of Mbale a degree of caution is required when interpreting these results because the inventory was carried out just after the water treatment works had been extensively damaged and a system of rationing was in place.

It is not unexpected that piped water sources were more prone to interruption than any other form of water source and this has been reported by Lloyd et al. (1991) in Peru. The degree of difference in reporting of discontinuity with protected point sources was significant and illustrates that in a number of cases there were major supply problems in piped water supplies. The relatively limited reporting of discontinuity in point sources indicates the value of such supplies, but is somewhat surprising because a significant number of such sources in several towns were boreholes where interruption would have been expected due to downtimes associated with breakdowns and repairs (Taylor, 1993). The much higher reporting of interruption in unprotected sources shows that these are less reliable and is likely to be a factor in the relatively low usage of such sources.

The water usage studies in Kampala and Soroti suggest that users experience higher levels of interruption to supply than found in the inventories, although these sets of data cannot be directly compared as the inventory focused on water sources and the water usage study on households.

The reporting of discontinuity by households in the water usage study was also different to that found in the sanitary inspections. As noted in section 6.5.3, this is likely to be because the water usage data indicates that discontinuity occurs only occasionally, whilst the sanitary inspections dealt with discontinuity over a much shorter time period. In Soroti, nearly 60% of piped water users reported interruption in the water usage studies, although the majority of responses indicate that this
happened only occasionally. Nonetheless, there is a significant variation in the data that is not seen for Kampala suggesting that there may have been some bias in the sanitary inspection data collected in Soroti.

7.9.1 Protected point and unprotected sources

Overall, protected point sources show limited interruption in supply and much lower than either the piped or unprotected sources. In the case of the protected springs, this is not surprising as a continuous yield is an important component of design criteria (Jordan, 1980). The continuity of the protected springs does not, however, indicate that these were well maintained as shown by the high sanitary risk scores in section 5.3.2. Continuity in boreholes appears also to have been good. This is likely to reflect that the fact the boreholes were well maintained, which would be supported by the overall lower sanitary risk scores noted in section 5.3.1.

The unprotected sources were a mixture of shallow groundwater (springs and scoop wells) and surface water (Barrett et al., 2000a; Howard et al., 1999; Taylor and Howard, 2000). In the shallow groundwater sources, it is likely that part of the reason why springs remained unprotected was that year-round flow could not be assured and therefore it is not surprising that proportionately more of these sources have interruption in supply. The scoop wells are very shallow excavations to the water table and are susceptible to periodic drying-up. In the case of the surface water sources, interruptions are primarily related to drying during the dry season, although this does not necessarily occur every year and in some cases only in years of extended dry periods.

7.9.2 Continuity in piped supply

The data for piped supply shows considerable variation and show that continuity in supply is less predictable than for point or unprotected sources. The sanitary inspection data for piped supplies shows that interruption in supply was common in most towns. Interruption seems to have been more common in NW&SC supplies and there was a median frequency of reporting of 19% in these supplies, with a range of 9.2% to 29.0% as shown in table 6.25.
The problems in most towns were related to inadequate system storage and in some cases increasing demands placed on the water supply by increased development of higher-income houses (Stephens, 1996). The latter certainly appears to be true in Mbarara, which had a much higher rate of discontinuity than other towns, and where there was substantial economic growth and consequent building of larger properties with greater water requirements.

The relatively low frequency of reporting of interruption in Kabale and Soroti as shown in table 6.25, is somewhat surprising as these systems were both known to have significant problems. These results may reflect the fact that there were limited numbers of users and therefore demand and supply were better balanced.

In Kampala improvements in continuity over the period of study as shown by reducing reporting of discontinuity as shown in Annex 12, although the extent of reduction varied between Divisions. The improvements in supply continuity reflected a response by the water supplier to the data being collected by the surveillance staff. The cause of the discontinuity in these supplies appears to have resulted primarily from inadequate system storage in service reservoirs and likely losses from leakage.

In Makindye and Nakawa Divisions, relatively high rates of discontinuity were found throughout the study and actually increased in Makindye towards the end of the study period. This suggests that there were problems due to losses of water through leakage and that storage capacity to meet peak demands was not adequate to meet increasing demands. As noted by Zerah (2000), this is of particular concern in low-income communities where the household capacity to cope with interruption is limited.

In the case of Mbale, as noted above, the initial high rates of interruption recorded in the inventory could be related to a period when rationing had to be practised as the treatment works had been severely damaged during the wet season 1997/98. Once this problem was resolved (which occurred by mid-1998) the supply became more continuous, although 21% of sanitary inspections recorded interruption in supply and this varied between 20 and 30% during the four quarters of 1999. In the other towns, the percentage of sanitary inspections where discontinuity was reported varied
between sampling rounds, but in general remained close to the average overall reporting of discontinuity throughout the study.

The community managed piped water supplies in Kabale showed very little interruption in supply. In the inventory many the taps connected to such systems were noted as having occasional interruption, suggesting periodic problems either with source or problems in the distribution systems.

As shown in Section 5.2.4, continuity is of particular importance in relation to potential for contamination of piped water supplies and it was only for these sources that data were collected in Uganda through sanitary inspection. The importance of discontinuity in the NW&SC supplies is shown in table 5.15 and appears to be more important in causing contamination in Municipal supplies.

7.9.3 User experience of continuity

The reporting of continuity (as expressed by the term reliability) was significant for most water source types (whether as first or second choice sources) in both Kampala and Soroti, indicating that continuity remains an important criterion for users in their perceptions of the adequacy of the supply to meet their needs. This finding is similar to those reported by Howe and Smith (1994) and Kwietniewski and Roman (1997).

Despite the relatively high frequency of citing continuity as a reason in source selection, the data shown in tables 6.12 and 6.13 indicate that in both Kampala and Soroti this was relatively low in the priorities assigned to water supply characteristics by most households. This is likely to have been because users of communal supplies were in situations where multiple source options existed within reasonable distance, at acceptable costs and acceptable perceived qualities. In such situations, the importance of continuity may be lower, as households already use multiple sources. It is also likely to reflect the fact that in both towns the available water sources were not subject to large-scale discontinuity, as shown by the data from the inventories, water usage studies and sanitary inspection data presented in section 6.5.

In the water usage study in Kampala, the reporting of reliability as a reason for
selecting first and second choice sources (particularly the use of taps) was unevenly spread between different Divisions, however, there was little evidence of increased multiple source use among households in these two Divisions compared to other Divisions. It is likely that the discontinuity in supply was not evenly spread even within relatively small areas and as a result households used taps that were known to be more continuous.

The continuity in supply of protected springs may be a reason why these sources continued to be used by many low-income households (Almedom and Odhiambo, 1994; Fass, 1993; Madanat and Humplinck, 1993). The results from the study in Uganda indicate that continuity as a reason operated most positively in the use of non-piped sources. However, the limited difference in reporting between different source types suggests that whilst continuity is of general concern, it may have had less importance in determining preferences for particular water sources.

7.9.4 The value of continuity as an indicator

In relation to the influence of discontinuity on water quality, the analysis of data from the NW&SC supplies shown in section 5.2.4.3, shows the importance of monitoring discontinuity as the association with thermotolerant coliforms is significant to above the 99% confidence level. Discontinuity is also included in the logistic regression model for thermotolerant coliform presence in the NW&SC supplies shown in table 5.15.

This provides good evidence of the importance of continuity as an indicator for piped supplies and would concur with the conclusions of Clark et al. (1993b), Geldreich (1996), Kirmeyer and LeChevalier (2001) and Regli et al. (1991). The lack of significant association between discontinuity and microbial contamination in the Municipal run supplies in Uganda shows that such strong associations are not always found, although this does not invalidate the conclusion regarding the importance of continuity in protecting microbial quality.

In terms of the impact on users, the data from the water usage studies provide less good evidence of its importance for users. Although reliability (as a surrogate for
continuity) was cited by a relatively large number of respondents in the water usage studies in both Soroti and Kampala, it was less important than other reasons. This is in contrast to the conclusions drawn by other workers (Howe and Smith, 1994; Kwietniewski and Roman, 1997; Zerah, 2000).

This may be explained by the conditions of water supply in urban Uganda where multiple sources of water were available and used and the continuity in piped supplies was generally good. As a result, the selection of water sources used by low-income households was driven by many different factors.

It is likely that in other settings continuity may be more important in source selection, especially where discontinuity is more common, of longer duration and where there are limited alternatives (Zerah, 2000).

7.10 Leakage

The data from Uganda show that qualitative measures of leakage can be collected via sanitary inspection. Although it is clear that more detailed analysis of quantitative measures of leakage would have assisted in the analysis of water quality failure and operation and maintenance, as noted in Chapter 2 this would not be possible for a surveillance body to undertake. The role of surveillance programmes would therefore primarily be to encourage water suppliers to undertake such analysis and take steps to reduce system losses (Chowdhury et al., 1999; WELL, 1998; Xie et al., 1993).

The data shown in Section 6.6 show that in Kampala, Soroti and Tororo signs of leakage reduced. This was most noticeable in Kampala and Soroti. In Kampala reporting of leakage reduced from 52% of sanitary inspections to only 16% and in Soroti from 47% to 0%. The reduction was less marked in Tororo. In Mbale no improvements were found. Reductions in reported signs of leakage were seen in Jinja and Mbarara, but no obvious reductions in Entebbe or Masaka. The limited data from these supplies, however, make it difficult to draw firm conclusions.

The reductions in signs of leakage in Kampala and Soroti may be partly ascribed to the role of the surveillance staff in reporting leaks to the water supplier and working
with communities to improve maintenance in the tertiary infrastructure. In Soroti in particular, the links made between the surveillance and water supply staff yielded improvements in leakage reductions. In Mbale, however, very little improvement was noted during the study suggesting that these links were not effectively made. Intra-urban variation seen in Kampala and Mbale noted in section 6.6 also indicates that reductions in leakage were not uniform across these supplies.

7.11 Quantity

The results obtained from the water usage studies in the three towns regarding the quantities of water collected by households shown in section 6.7 show that there was little influence of water source type or climatic conditions on volumes of water collected. As the households interviewed in the water usage studies lacked a household connection, these findings reinforce the conclusion reached in Section 2.2.4 that the quantity of water collected only changes with differences in service level. The plateau effect described by Cairncross (1987) appears to operate in urban areas of Uganda and it can be concluded that once water is external to the house, but within reasonable distance, little change is seen in quantities of water used (Cairncross, 1990b).

There is potential confounding of the results as the water usage studies were all undertaken during the dry season and it may be possible that the volumes of water collected would vary with season, as suggested by White et al. (1972). However, in Kampala and Masaka, where rain falls throughout the year, it can be hypothesised that such obvious climatic effect would be less likely to occur. Soroti has a more pronounced dry period and thus could possibly show such variation, although this remains uncertain.

Other work discussed in section 2.3 has highlighted the influence of cost on quantities of water collected (Thompson et al., 2001; WELL, 1998). The data from the study in Uganda shown in section 6.7 indicate that there is no significant difference in quantities of water in relation to the requirement to pay in Kampala. This demonstrates that cost of water does not influence the quantity of water collected within the city. A similar conclusion is drawn from the analysis of water quantity data.
from Masaka and Soroti. In Soroti, the largest volumes of water collected are from taps, where payment was more likely to be required and thus cost cannot be viewed as influencing the quantity of water collected. In Masaka, although water quantities from taps appear significantly lower than from unprotected springs and ‘other’ sources (scoop wells and other unprotected sources) they are significantly higher than from protected springs, despite the latter being free.

The only evidence that supports the theory that cost will reduce quantities of water collected is the difference in quantities collected between NW&SC supplies and Municipal run supplies shown in section 6.7. It is likely, however, that the difference between the NW&SC and Municipal supplies is due to the nature of the ‘communal’ taps. In Masaka and Kampala, tap water is either purchased from public taps or from on-sellers, while in Soroti communal taps provided a landlord on a compound serving a small number of households were the usual form of piped supply. The latter is largely equivalent to a yard-level of service and suggests that access taken from inventory data could be used as a surrogate for differences in quantities used. This may not be found in other settings and this represents an area where further work appears justified through well-formulated studies such as those used in Uganda.

In terms of public health gains, the influence of quantity is not easy to quantify. There is clear evidence that improvements in access as determined by service level do provide incremental health gains (Esrey et al., 1985; Esrey et al., 1991; Esrey, 1996; Howard and Bartram, 2002). Increased service levels of water supply should make good hygiene easier to practise and as noted in Chapter 2 previous research points in particular to the sensitivity of child washing in relation to distance of water collected (Prost and Négrél, 1989; Prüss and Mariotti, 2000; West et al., 1989; West et al., 1991; Zerihun, 1997).

However, where water supply is beyond the immediate environs of the home, it is the use of water and specific hygiene behaviours that dictate health gains. Evidence for this was discussed in section 1.4 and is shown in studies by Huttley et al. (1997). This therefore suggests that monitoring of hand-washing with soap would be more important for assessing the influence of hygiene on diarrhoeal disease than quantity of
water collected. The same conclusion is apparent from the literature review in relation to trachoma (Bailey et al., 1991; Prüss and Mariotti, 2000; West et al., 1989).

Public health gains can be expected in relation to increases in service level, however, as discussed further below this may not be simple to achieve as it raises further issues regarding policies for water supply provision and cost-recovery. Furthermore, increases in service in Uganda are dependent on the degree to which households choose to invest their capital in water supply services. For households that remain with only communal levels of service, the incremental public health gain derived from hygiene would be facilitated more effectively by promoting the uptake of hygiene practises, including safe handling of water used for consumption. It can be concluded, therefore, that quantity of water collected in terms of volumes is largely unnecessary for surveillance programmes and that service level acts as reliable surrogate (Bartram, 1996; Howard and Bartram, 2003).

### 7.12 Linkages between surveillance and improvement

Many of the mechanisms by which the surveillance programme contributed to improvement in water supplies have been discussed in the preceding sections of this chapter. This section therefore tries to summarise these and presents a discussion of key points for developing improvements in water supply that arose as a result of the programme of study.

#### 7.12.1 Water quality standards and regulation

In many urban water supplies, the development and enforcement of standards of drinking water quality are often desired as it is believed they offer a means of ensuring that risks to public health are managed at an appropriate level (Helmer et al., 1999; Solsona, 2002; WHO, 1993). Steynberg (2002) notes that although most countries have drinking water quality guidelines or standards, in developing countries these are rarely enforced.

In Uganda, there were no legally binding standards for drinking water supply during the period of study and the surveillance programme did not seek their development. The reasons for this are clear from a review of the data on the use of water supply and
the programme of water quality monitoring undertaken for non-piped water supplies. The data on water usage clearly show that use of non-piped water supplies among poor households was significant. The alternative supplies were in most, but not all cases, of worse quality and represented a more significant risk to public health than the piped water supply. The association between the use of multiple sources and incidence of diarrhoea has been shown in section 6.3.2, as has the association between the vulnerability of communities (as described by the zone categories) with cholera cases in section 4.4.1. Furthermore, the data in section 5.4 shows that despite improvement in the quality of water stored in households, significant re-contamination occurred.

Standards would have related to the piped water supply and it is unlikely that standards could have been enforced for non-piped water supplies. In part this relates to the fundamental problems in applying standards and regulations to supplies that are managed by the communities that they serve. Problems immediately arise in such circumstances about liability and the degree to which trying to enforce standards of quality would immediately undermine the basic principles of community management (Bartram, 1996; Howard, 2002; Ince and Howard, 1999).

In Uganda, the application of drinking-water quality standards would therefore have had limited impact on overall public health risks. Indeed they may be counter-productive as the application of standards may have forced operational changes that could lead to increases in tariff and further limitations on access (Ince and Howard, 1999). These problems mirror broader problems of trying to apply regulations on water quality without taking due account of current socio-economic conditions (Helmer, 1987). In Uganda, there would have been little point in applying standards for drinking-water quality unless these were balanced by binding regulations on tariff, increasing uptake of services and programmes to reduce post-source contamination.

At the time of the study although there were some regulations relating to access and tariff, these were not enforced and little was done to ensure that problems of low uptake were addressed.

Drinking water quality standards have been developed in similar countries within
Africa, notably in Ghana, in response to the leasing of water supplies to private operators (Ince and Howard, 1999; WEDC and RCPEH, 1999). The development of a cost-effective approach to regulation demands consideration of priorities for water quality and control (Howard, 2002). Models based on audit approach appear to offer a significant benefit when enforcing water quality standards in utility supplies (Howard, 2002; WEDC and RCPEH, 1999). However, the development and enforcement of drinking water quality standards should be balanced by the need to increase access to household connections and in developing local surveillance activities to address community-managed water supplies and improvements in water handling (Howard, 2002; Ince and Howard, 1999; WEDC and RCPEH, 1999).

7.12.2 Technical improvements

Within the programme of study a number of key linkages were made to improve the operation and maintenance of water supplies. The majority of these have been highlighted within the discussion of water quality and focused on:

- reductions in discontinuity;
- improvements in flushing and maintenance of systems;
- identification and repair of major leaks in piped supply; and,
- maintenance by community operators.

The resolution of discontinuity required two strategies by the water supplier which were being implemented. The first was to ensure that source production could meet demand and that there was adequate system storage to cope with peak demands. Such intervention strategies clearly will take some time to implement, but the surveillance data were important components in informing this strategy and indicating areas of priority (Lloyd and Bartram, 1991; Lloyd et al., 1991). The second action was to reduce leakage, a factor related more directly to operation and maintenance. The implementation of the surveillance programme yielded improvements seen in Kampala with reducing interruption in supply, as shown by the reduced reporting of these risk factors in sanitary inspections between the third quarter of 1998 and the fourth quarter in 1999.
The data from the water quality analysis of piped supplies shows a general improvement that can be related to the recommendations by the surveillance programme to promote more effective maintenance of distribution systems and free chlorine residuals (Lloyd and Bartram, 1991; Howard, 2002). This was noted as being more successful for NW&SC supplies. This resulted from the greater pressure that could be exerted by an independent surveillance agency on a water supplier. In the Municipal supplies, where problems were more profound, improvements were more difficult to achieve in part because surveillance and supply fell under the same organisation. However, improvements in these supplies would have required substantial improvement in treatment works and expansion of staff that the surveillance programme could recommend but not ensure that this occurred. It is important to note that the consistent recommendations made by the surveillance team for NW&SC to take over Municipal supplies were taken up.

In the point water supplies, improvements were seen in the maintenance of many sources, although this proved more problematic in higher-density areas in Kampala. However, the re-protection of springs proved to be successful in reducing contamination and the training provided improved operator understanding of maintenance needs (Howard et al., 2001a). The design used became a recommended model for all re-protection works of springs in urban areas of Uganda. Similar projects were undertaken in Tororo that also provided significant improvements in water quality. In Masaka and several other towns, improvements were seen in the sanitary condition of protected springs, but the poor design meant that it was not possible to achieve the same level of improvement in microbial water quality (Howard et al., 2001a).

7.12.3 Hygiene education

The role of surveillance in promoting the uptake of good hygiene practices has been shown to be effective in relation to water handling (Pinfold, 1990; WHO, 1997). The results from Uganda suggest that this can be effective where surveillance is used as a participatory learning tool. Reducing levels of water contamination found in most towns suggests that surveillance activities were effective in promoting better hygiene practices. The lessons learnt from the surveillance project were formalised into a set
of hygiene education materials linked to a Participatory Health and Sanitation Transformation (PHAST) programme (WHO, 1996b).

Hygiene education programmes are usually designed to ensure that behaviour change is achieved within the target population and that this is maintained (Boot and Cairncross, 1993; Ferron et al., 2000). In relation to water handling, such an approach would require ensuring a shift to sole use of a safe source for drinking purposes and assuring good handling practice.

The evidence from Soroti and to a more limited extent Kampala, suggests that the former can be achieved, although this was undoubtedly easier in Soroti where the best quality source was essentially free of charge and relatively accessible. The shift to good handling appears more difficult to sustain, as shown in Soroti by the lack of improvements in household water quality. One of the major problems in all towns was to try and convince households to seal Jerrycan only with plastic screw caps rather than other items such as unripe bananas and wood. It was also difficult to persuade users not to clean the Jerrycans at the source with material from drainage ditches, as this seemed to be an ingrained behaviour.

In Kampala, the reduction in contamination of water stored in households indicates that the health education messages regarding safe water use were having an impact. In particular the supporting role of testing household water quality and feedback of results to households was found to be important to achieve a better quality of water. However, the degree of success of this approach was uneven. For instance, whilst the range of contamination found reduced in all Divisions except Makindye, the upper values of faecal contamination found remained high in Kawempe and Nakawa Divisions.

The evidence from Kampala suggests that focusing on reporting of results and on promoting household treatment may yield the most promising results. However, it is debatable whether promotion of boiling as a long-term strategy is effective and indeed has other adverse environmental health consequences caused by air pollution and loss of bio-resources (Budds et al., 2001). The evidence suggests that whilst boiling is
likely to be practised by more households during an epidemic (such as the cholera outbreak in 1997/98) sustaining this, even during outbreaks, is difficult (Sobsey, 2002a; Howard, 2002).

The reasons for the lack of sustained boiling are likely to derive essentially from the cost to the household of routine boiling of water. The energy requirements to boil significant quantities of water are high and given that likely daily consumption will be in the region of 1-2 litres per capita, this translates into a high household expenditure on kerosene and other energy sources. Given that the low-income group has many competing demands on limited household budgets, these costs may be perceived by households as unnecessary for much of the time (WELL, 1998). It is likely that compliance with boiling will be much higher during and in the immediate aftermath of an epidemic as such events represent crises for the family. Outside such events, the perception of households may be that the importance of boiling is greatly reduced. Alternative approaches to household water treatment using chlorine tablets and on-site chlorine generation have been successfully used in other developing countries, with significant reductions in diarrhoeal disease ranging from 25 to 90% (Sobsey, 2002b). Such approaches would seem to be viable in Uganda and would warrant further investigation.

7.12.4 Policy for water supply in urban areas

The data from the surveillance programme were able to influence policy in a number of ways and in particular by achieving recognition that social provision through public taps alone would not deliver significant improvements.

The data on cost of water and the relationship between tap use and multiple source use indicate that social provision through public taps overall did not yield significant health benefits for the urban poor. Tap users were also more likely to use multiple sources, which was associated with higher incidence of diarrhoea. The provision of public taps was important, however, in the control of the cholera epidemic in 1997/98.

In common with reported practices in other urban areas of developing countries, the majority of users of piped water among household without their own connection in
the towns included in the study collected water from ‘on-selling’ (Morris and Parry-Jones, 1999; Tatietse and Rodriguez, 2001). Intervention strategies should therefore investigate how ‘on-selling’ could be used to the benefit of the poor. This may include using public taps as a mechanism to reduce purchase prices or to formalise the local markets in water and use incentives for households to provide water at lower costs to their neighbours. However, it is far from clear whether such a strategy would be effective and would ultimately prove difficult to monitor and to enforce standards relating to price. In the long-term more emphasis is required to increase uptake of household connections or development of ‘shared taps’ similar to the taps provided by landlords in Jinja and Soroti (Sansom et al., 2000).

Within the policy environment, the data from the surveillance programme were used to initiate a shift in water supply policy to include improvement of point sources. Municipal Councils in particular were able to implement improvements in protected springs on the basis of this data and in the case of activities in Kampala and Tororo, re-protection of springs was undertaken (Howard et al., 2001a).

The policy was influenced by the analysis of water quality and sanitary inspection data that showed sanitary completion measures to be of greatest importance in controlling contamination of protected springs. This information was used as a justification for improvement in these sources where this reflected community demands. This would not have been the case had sub-surface leaching of microbial contaminants been the principal cause. In such a scenario, it would have been difficult to ensure improvements in water quality without reducing the scope to promote improved sanitation and it would have been more cost-effective to provide public taps.
Chapter 8

Conclusions and recommendations for future work

8.1 Introduction

This chapter presents the conclusions of the study in Uganda and literature reviewed and provides a brief overview of issues that require further research.

8.2 Conclusions

1. The aim of this study was to develop a model of water supply surveillance for urban areas in developing countries, with particular emphasis on the urban poor. The study in Uganda has shown that surveillance programmes can be developed for these settings and provides a framework that allows reliable and accurate information to be collected which will assist decision making. Both the project in Uganda and previous experiences in developing countries have shown that surveillance programmes generate information for improvement of water supplies for the urban poor. Within the surveillance programme developed in Uganda, a phased approach to surveillance programme development is found to be essential
for successful implementation. The development of surveillance programmes is summarised in figure 8.1 below.

**Figure 8.1: Development of urban surveillance programmes**
1.1 Decentralisation of surveillance to local levels is important to ensure that regular monitoring can be effectively carried out. Decentralisation also offers greater potential for defining locally appropriate solutions to identified problems. For water quality monitoring, developing local capacity for analysis is crucial to avoid problems with sample deterioration. The development of capacity in local government to implement surveillance programmes is essential if programmes are to be successful. The results from Uganda indicate that local staff, often with relatively limited academic training, can undertake surveillance effectively. Furthermore, staff with a background in environmental health and with experience of working with communities are best placed to be able to utilise surveillance data in generating solutions to water supply problems at a local level.

2. Within the study, the review and testing of indicators of water supply adequacy were important objectives. The project in Uganda has shown that a number of indicators of water supply are of value and data on these can be acquired. The study shows that surveillance programmes should collect data on a wide range of indicators of water supply adequacy. Focusing on a single indicator, for instance water quality, would fail to provide an overall view of public health risks associated with water supply. Incorporating user perceptions within the evaluation of the data generated on the selected indicators can also be concluded as important, as shown by the data collected in Uganda through the water usage studies. Furthermore, the results from Uganda show that data on selected indicators should be collected on all the water sources used by the population and not on one particular type of water source.

2.1 The quality of water is an important indicator for inclusion in surveillance programmes and within this priority should be given to microbial quality. Chemical parameters should be included where particular problems are known to occur or are suspected to be present. Although problems are noted with the use of thermotolerant coliforms, the study in Uganda confirms their utility, but indicates that a broader range of parameters relating to microbial quality are important. Furthermore, the use of other
microbial indicators is noted as important in order to gain a clear indication of risks associated with non-bacterial pathogens.

The results from Uganda indicate that the use of portable on-site testing kits is an effective means to ensure that water quality monitoring can be undertaken at local levels. This allows for greater numbers of samples to be taken and reduces the problems with sample preservation. The development of additional analytical facilities is a secondary priority. In the first instance, there is some justification for more sophisticated laboratories at national level that permit a greater range of analyses to be performed and that can support more detailed research. Wherever possible, however, existing analytical facilities should be used rather than development of new facilities.

Sanitary inspections are an essential complement to water quality analysis and provide data that can indicate the causes of contamination (when found) and provide an overview of operation and maintenance performance. The combined analysis of sanitary inspection and water quality data is important in identifying the principal influences on microbial water quality and in directing interventions. The results from Uganda indicate that detailed analysis investigating associations between individual risk factors and water quality is most effective when assessing the causes of contamination and in developing interventions that will yield the greatest improvements in water quality.

The data from Uganda show that in piped water supplies, preventive maintenance and reduction in sanitary risks are essential components of water quality control. Reliance on chlorination without complementary maintenance is ineffective in providing assurance of good microbial quality. The data from Uganda indicate that water suppliers need to place greater emphasis on good system management to reduce risks and to monitor this through sanitary inspection.
Maintaining water quality in point sources is dependent on the maintenance of water sources, but may also be influenced by the technology used and the surrounding environment. Boreholes provide water of better microbial quality than springs. For protected springs, maintenance of the sanitary protection works is critical and in Uganda far more important than controlling source of faeces. The results from Uganda indicate that support is required by communities to improve maintenance of point sources. The association with population density indicates the importance of disposing of excreta within high-density areas to prevent contamination.

Well-designed studies of a representative sample of point sources yield better data for investigation of causes of contamination, and therefore improvement strategies required, than routine monitoring of large numbers of point sources.

Testing of water stored within the home is important, particularly for households that use communal sources. Re-contamination is a common problem and may undermine health gains accrued from improvements in water sources. Surveillance programmes can use water quality testing as a hygiene education tool and this is effective in promoting improvement in household water quality.

2.2 The collection and analysis of data on availability of water sources and access to water supplies is important when developing surveillance activities. The use of inventories to collect data on sources available to households that lack a connection was found to be valuable in Uganda and can be concluded as essential for all surveillance programmes. The data collected from inventories provide an indication of the complexity of water source availability and, in the case of Uganda, showed that 'on-selling' of water by households with a connection to the piped water supply is very common. Review of the number of connections to the piped water supply is important, although the study in Uganda shows the
difficulties that are encountered in collecting and interpreting this data. It can be concluded that surveillance agencies should ensure that reliable data are made available from water suppliers, in order to develop appropriate field data collection exercises.

2.3 Data on use of different water sources among low-income households are essential to determine the importance of different water sources to low-income households. These data are important both in defining the need for, and frequency of, monitoring of different water sources and identifying improvement strategies. It is concluded that water usage studies are an important component of surveillance programmes.

2.4 Cost is an important indicator for water supply surveillance and data can be collected by simple means through inventories and water usage studies. This study also demonstrates that when assessing costs of water in low-income communities, data should be collected on the actual cost of water at the point of purchase rather than on published tariffs. The collection of data on tariffs remains of value only insofar as it permits evaluation of the discrepancy between charges and costs to the users.

Costs of water at the point of purchase are usually greater than those applied by the utilities in Uganda and the literature indicates that this is commonly the case in urban areas of developing countries. The project in Uganda demonstrates that social provision of piped water provided limited cost-savings to low-income households. In general costs at public taps matched those of 'on-sellers' indicating that local market forces set prices rather than social policy. In Uganda, the collection of data on estimated costs of connection was of value in demonstrating the difficulties faced by low-income households in acquiring their own connection.

2.5 Continuity is an important indicator for surveillance programmes. The evidence from the analysis of contamination of NW&SC supplies in
Uganda supplies demonstrates the importance of continuity in controlling microbial quality of piped water. The evidence from Uganda demonstrates that data on continuity in piped water supplies can be easily and rapidly obtained through sanitary inspection.

The evidence from Uganda of the importance of continuity for households provides rather contradictory data. Although continuity (as expressed by 'reliability') was given as a reason for selection of water sources, it was less important than many other reasons. This suggests that whilst continuity is part of the decision-making process, it is not particularly important.

The situation in Uganda, however, may not be typical of other urban areas in developing countries, as there were numerous other water sources deemed acceptable by low-income households. In other situations with more limited available alternative water sources and where discontinuity was more common, user perception of the importance of continuity would be expected to increase and therefore data would be of value.

2.6 The quantity of water used by households is noted as important to health, although the effective use of water is more important for households using communal sources. The evidence from this study and the literature demonstrates that quantities of water used only change in relation to the level of service. Therefore estimates of the quantity of water used are most readily obtained through data collected regarding service level rather than directly measuring quantities of water used. The data from the project in Uganda show that the quantity of water used by households without a connection is on average under 20 litres per capita per day, a figure that agrees with previous published studies. There is little difference noted in quantities of water collected between towns and in most cases between source types.
In Uganda there was little evidence that either continuity or cost of water influenced the quantity of water collected. Where either continuity or costs was perceived as unacceptable by low-income households, changes in source selection resulted rather than reductions in quantities of water collected. This is again influenced by the wide availability of alternative sources for low-income households.

In situations where there were fewer alternative sources and there is greater discontinuity or costs are higher than willingness to pay, reductions in quantities of water used may be found. In such cases, estimates of continuity and cost may be sufficient to provide an indication of likely the quantity of water collected.

2.7 The study has shown that estimates of leakage are of value when investigating water quality. These data can be easily obtained through sanitary inspection, but can only be qualitative estimates of leakage. However, the study does not suggest that surveillance bodies should undertake quantitative estimates of leakage, but that they should advocate for these data to be collected by water suppliers.

3 Identifying appropriate institutional arrangements for surveillance was a further objective in this study. The study has shown that the Health sector can be effective in undertaking surveillance programmes. The use of the Health sector ensures that data collected are relevant to assessing water-related risks to health. In Uganda, the use of the health sector was further preferred because of the links that exist between national and local levels.

In situations where local environmental health staff are not available, consideration should be given to developing local cadres of staff able to perform surveillance and other environmental health functions. In some situations, consideration may need to be given to using a different sector to lead the surveillance activity. If another sector, for instance the environment sector, does take responsibility for surveillance, however, it is important that public health bodies play a role, for
instance in providing guidance on indicators of value to assessing water related risk to health.

Regular reporting of results and development of reporting for a range of target audiences, which should include communities, is critical to successful utilisation of surveillance data and should be prioritised within surveillance programmes. Reporting to each target audience should reflect the likely use of the information and use means that are accessible and appropriate.

4 The identification of measures of poverty was a key objective for the study. The inclusion of measures of poverty is important to ensure that surveillance activities target those that are most vulnerable. The project in Uganda indicates that quantitative socio-economic indices provide an effective way of incorporating poverty into surveillance programme design.

Including poverty within a broader system of urban zoning is particularly effective for larger urban areas. Combining population density and means of water supply provision with measures of socio-economic status has been shown to be effective in determining priority areas in relation to vulnerability to adverse health outcomes. Urban zoning provides a mechanism for targeting activities in those areas that are most vulnerable to water-related disease and for identifying which water sources require testing. However, although it can be concluded that urban zoning is an important aspect of surveillance, its value is greatest in larger urban areas with a wider range of communities and socio-economic status.

5 The linkage of surveillance data to improvement of water supply and analysis of surveillance data were identified as key objectives at the outset of the study. The experience of improvement in operation and maintenance of water supplies in Uganda has shown that effective linkages can be made between surveillance data and water supply improvement strategies. The detailed analysis of surveillance data is important to identify which improvements will have the greatest impact and has been discussed in relation to the specific indicators.
The use of these data in improving household water handling and in developing improved designs for alternative supplies provide examples of how such analysis aids decision-making. Understanding which water sources are used by low-income households and the reasons for source selection are important when developing strategies to improve water supply.

8.3 Recommended further research

A number of areas have been identified where further research, building on the findings of this research project, is recommended. These are described briefly below and ongoing work identified. These are in addition to a general recommendation that more experience with implementing surveillance programmes in urban areas of developing countries is required.

Testing other approaches to urban zoning is one area where further research would be beneficial. The approach used in Uganda worked well, but there is a need to investigate other, possibly more qualitative approaches. In countries where the detailed quantitative data used by the Uganda study is not available, other approaches need to be developed and tested. There is already interest within this area in Nepal and other developing countries.

Further research is required to develop more effective practices to manage and monitor water quality, which place an emphasis on process control and do not rely solely on the analysis of indicator bacteria. The Hazard Analysis and Critical Control Points (HACCP) approach used in the food industry provides a useful model for water supply safety management, as this emphasises process control and simple monitoring approaches that allow rapid rectification of faults (NACMCF, 1992). Shortly after HACCP was codified, Havelaar (1994) proposed its use in the water sector and subsequently this has been applied in several water supplies in developed countries (Barry, 1998; Deere and Davison, 1998).

There is increasing recognition that approaches similar to HACCP would be of use for water quality management and these are being formulated in an approach termed ‘Water Safety Plans’ (Davison et al, 2002). However, more research is required into
how these approaches can be implemented in both developed and developing countries. Work is currently ongoing in Uganda to develop such approaches for utility supplies (Howard et al., 2002c) and potential approaches have also been outlined for point systems (Howard, 2003).

The establishment of health-based water quality targets is an important further component in establishing Water Safety Plans (Davison et al., 2002). Previous work in the USA has used this approach, which sets performance targets in relation to pathogen concentrations (Haas et al., 1999; Regli et al., 1991). Further work is required within this area particularly in relation to developing countries, where transmission routes of infectious disease are complex (Howard et al., 2002c).

In addition to the above, the study in Uganda identified that sanitary inspection is difficult for urban piped water sources and that more sophisticated risk models were required to properly allow for monitoring of sanitary conditions. This is likely to involve investigation of the importance of hydraulic behaviour on water quality and defining vulnerability of pipe systems (LeChevalier, 1999; Howard et al., 2000c).

Further research is also warranted in the development of monitoring tools suitable for community use to allow better maintenance of water quality in community-managed supplies (Davison et al., 2002; Howard, 2003). Work is also required in developing better tools for monitoring sanitary conditions of household water storage containers and in defining the importance of re-contamination of water during collection and storage.
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