Domestic water quantity, service level and health

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Executive summary

The quantity of water delivered and used for households is an important aspect of domestic water supplies, which influences hygiene and therefore public health. To date, WHO has not provided guidance on the quantity of domestic water that is required to promote good health. This paper reviews the requirements for water for health-related purposes to derive a figure of an acceptable minimum to meet the needs for consumption (hydration and food preparation) and basic hygiene.

Based on estimates of requirements of lactating women who engage in moderate physical activity in above-average temperatures, a minimum of 7.5 litres per capita per day will meet the requirements of most people under most conditions. This water needs to be of a quality that represents a tolerable level of risk. This volume does not account for health and well-being-related demands outside normal domestic use such as water use in health care facilities, food production, economic activity or amenity use.

The basic need for water includes water used for personal hygiene, but defining a minimum has limited significance as the volume of water used by households depends on accessibility as determined primarily by distance and time, but also including reliability and potentially cost. Accessibility can be categorised in terms of service level. A summary of the degree to which different levels of service will meet requirements to sustain good health and interventions required to ensure health gains are maximised is shown in table S1 below.

Table S1: Summary of requirement for water service level to promote health

Service level	**Access measure**	**Needs met**	**Level of health concern**
No access (quantity collected often below 5 l/c/d)	More than 1000m or 30 minutes total collection time	Consumption – cannot be assured Hygiene – not possible (unless practised at source)	Very high
Basic access (average quantity unlikely to exceed 20 l/c/d)	Between 100 and 1000m or 5 to 30 minutes total collection time	Consumption – should be assured Hygiene – handwashing and basic food hygiene possible; laundry/ bathing difficult to assure unless carried out at source	High
Intermediate access (average quantity about 50 l/c/d)	Water delivered through one tap on-plot (or within 100m or 5 minutes total collection time	Consumption – assured Hygiene – all basic personal and food hygiene assured; laundry and bathing should also be assured	Low
Optimal access (average quantity 100 l/c/d and above)	Water supplied through multiple taps continuously	Consumption – all needs met Hygiene – all needs should be met	Very low

Table S1 indicates the likely quantity of water that will be collected at different levels of service. The estimated quantities of water at each level may reduce where water supplies are intermittent and the risks of ingress of contaminated water into domestic water supplies will increase. Where optimal access is achieved, but the supply is intermittent, a further risk to health may result from the compromised functioning of waterborne sanitation systems.

The public health gains derived from use of increased volumes of water typically occur in two major increments. The first relates to overcoming a lack of basic access, where the distances and time involved in water collection result in use of volumes inadequate to support basic personal hygiene and may be marginally adequate for human consumption.

Further significant health gains occur largely when water is available at household level. Other benefits derived from the second step in improving access include increased time for example, child-care and food preparation and productive activity. Health gains derived from increased access between these two major steps appear limited, although other gains in relation to increased time for activities such as child-care, food preparation and productive activity (including education) may be significant and progressive. Further incremental improvements may also occur at higher levels of service, associated with further increased access and drinking-water quality control, but also linked to improved socio-economic status.

Where the basic access service level has not been achieved, hygiene cannot be assured and consumption requirements may be at risk. Therefore providing a basic level of access is the highest priority for the water and health sectors.

Within the population served by basic levels of service, public health gains are primarily achieved through providing protected water sources, promoting good water handling hygiene practices and household treatment of water and in other key hygiene behaviours (notably hand and face washing) at critical times.

The categories of service level can also been understood in terms of household water security, although a full description of this would also require estimates of quality and safety. The group with no access have no household water security. The group with basic access could be described as having partial household water security, with the remaining groups described as having sustained household water security, dependent on the quality of water supplied.

The service level categories shown in table 1 should be compared with data concerning estimates of present level of coverage by service level as summarised in table S2 (WHO and UNICEF, 2000)[1]. These figures show that there remains a significant proportion of the world's population (18%) without access to an improved water supply within one kilometre of their dwelling and that 53% do not have access to an intermediate level of service as defined in table S1.

The figures for access to an intermediate level of service of water are lower than for sanitation (60%), for which definitions for reasonable access were all related to household or near-household levels of service. Currently there is, justifiably, significant advocacy to reduce the sanitation access deficit, however, this evidence suggests that to meet a more

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[1] Improved water supplies were: household connection, public standpipe, borehole, protected dug well, protected spring and rainwater collection.. Unimproved water supplies were: unprotected well, unprotected spring, vendor-provided water, bottled water, tanker truck provision

health-centred definition of access to improved water supply, equal attention is required for improvement in both water supply and sanitation.

Table S2*: Water supply access data for 1990 and 2000 by no access, access to improved sources and piped supply (from WHO and UNICEF, 2000)*

Year	No access (millions)	Access to improved sources within 1 kilometer (millions)	Access through household connections (millions)
1990	21% (1126)	38% (1981)	41% (2159)
2000	18% (1099)	35% (4956)	47% (2846)

The right to water exists at the level of the individual and implies access to the minimum necessary for basic needs. Progress towards universal achievement of this level of service is associated with substantial health gain and remains a focus on international policy initiatives through the Millennium Declaration Goals and of monitoring activities through the WHO/UNICEF Joint Monitoring Programme.

Where achievement of full access to a basic level of service has not been achieved, policy initiatives should address increasing the numbers of households with this level of service. Maximum health benefits are likely to be obtained by directing resources towards ensuring that all households have access to improved water sources, and in some circumstances in directly upgrading to access at household level (generally through piped means). Significant gains are also likely to be achieved by upgrading of those with access to improved sources to household level access. In contrast increasing ease of access to improved sources outside the household is likely to provide limited health returns. Assessment of progress towards this level of access should be a target of policy in all countries and in particular where basic needs have been met. Health and other benefits from improved water supply are significantly greater when there is a supply of continuous access to safe drinking water within the home, a level of service that can be defined as optimal.

In practice, the use of water for domestic purposes cannot easily be distinguished from productive use at the household level, particularly among poor urban communities. Domestic water use to sustain livelihoods among the poor forms an integral part of household coping strategies. There may also be important health and social gains from ensuring adequate quality of service to support small-scale productive use, for example where this involves food production. Access to water adequate for small-scale productive activity in such areas is therefore important as part of poverty alleviation and may deliver significant indirect health benefits as a result.

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1 Introduction

Domestic water supplies are one of the fundamental requirements for human life. Without water, life cannot be sustained beyond a few days and the lack of access to adequate water supplies leads to the spread of disease. Children bear the greatest health burden associated with poor water and sanitation. Diarrhoeal diseases attributed to poor water supply, sanitation and hygiene account for 1.73 million deaths each year and contribute over 54 million Disability Adjusted Life Years, a total equivalent to 3.7% of the global burden of disease (WHO, 2002). This places diarrhoeal disease due to unsafe water, sanitation and hygiene as the 6th highest burden of disease on a global scale, a health burden that is largely preventable (WHO*,* 2002). Other diseases are related to poor water, sanitation and hygiene such as trachoma, schistosomiasis, ascariasis, trichuriasis, hookworm disease , malaria and Japanese encephalitis and contribute to an additional burden of disease.

As of 2000 it was estimated that one-sixth of humanity (1.1 billion people) lacked access to any form of improved water supply within 1 kilometre of their home (WHO and UNICEF, 2000). Lack of access to safe and adequate water supplies contributes to ongoing poverty both through the economic costs of poor health and in the high proportion of household expenditure on water supplies in many poor communities, arising from the need to purchase water and/or time and energy expended in collection. Access to water services forms a key component in the UNDP Human Poverty Index for developing countries (UNDP, 1999).

The importance of adequate water quantity for human health has been recognised for many years and there has been an extensive debate about the relative importance of water quantity, water quality, sanitation and hygiene in protecting and improving health (Cairncross, 1990; Esrey *et al.*, 1985; Esrey *et al.*, 1991). Despite this debate, international guidelines or norms for minimum water quantities that domestic water supplies should provide remain largely lacking. For instance, whilst the Millennium Declaration Goals include a target to *'halve the proportion of people who are unable to reach or to afford safe drinking water by 2015'* (UN, 2000) it does not specify in what quantity such water should be supplied. The WHO/UNICEF Joint Monitoring Programme, which produces the Global Assessment of Water Supply and Sanitation data, describe reasonable access as being *'the availability of at least 20 litres per person per day from a source within one kilometre of the users dwelling'* (WHO and UNICEF, 2000). However, it should be noted that this definition relates to primarily to ***access*** and should not necessarily be taken as evidence that 20 litres per capita per day is a recommended quantity of water for domestic use.

Norms for quantities of water to be supplied have been proposed for certain specific conditions. For instance the SPHERE project sets out 15 litres of water used per capita per day as being a key indicator in meeting minimum standards for disaster relief (SPHERE, 1998). In their guidance manual prepared for the Department for International Development (UK), WELL (1998) suggested that a minimum criterion for water supply should be 20 litres per capita per day, whilst noting the importance of reducing distance and encouraging household connection. A similar figure has been suggested by other researchers (Carter *et al.*, 1997). Gleick (1996) suggested that the international community adopt a figure of 50 litres per capita per day as a basic water requirement for domestic water supply.

Many uses of water occur largely at the household (for instance drinking, eating and hand-washing); others may occur away from the home (laundry and in some cases bathing). This therefore needs to be borne in mind when ensuring that adequate quantities of domestic supply are available for these purposes and in interpreting and applying minimum values.

Despite common claims of WHO standards relating to water quantity, WHO has not previously published specific guidance on the quantities of water as targets for the health protection and promotion. This is in contrast to the concerted effort made, for example, in relation to establishing international standards and later guidelines for drinking-water quality (WHO, 1985; 1993), wastewater use (Mara and Cairncross, 1989) and recreational water quality(WHO, *in finalisation*).

It is important to distinguish quantities of water required for domestic purposes (which primarily influence health and productivity), and quantities of water required for other purposes (such as agriculture, industry, commerce, transport, energy and recreation). Overall, the requirements for domestic supply typically constitute a very minor component of total water withdrawals (Gleick, 1993; 1996).

The purpose of this paper is to review the evidence of the relationships between water quantity, access and health and to provide a basis for the establishment of minimum quantity and/or access targets for domestic water supplies. It does not address the requirement of waters for specific groups (e.g. athletes), specific settings (e.g. hydration needs during air travel or particular occupational settings) or health impacts related to hydration derived from alcohol consumption.

The paper draws on an extensive literature review based primarily on the published literature, but in some cases also drawing on 'grey' literature where the data was believed to be of good quality and where this provided clearer information. Key word searches in Cambridge Scientific Abstracts (including Aqualine, Water Resource Abstracts and Bacteriology Abstracts) and Medline were employed. In addition, a review was undertaken of available materials (papers, books, theses, conference proceedings) at WEDC and WHO resource centres. A representative literature was captured through this process, although as noted within the text in some areas available literature and evidence is sparse.

2 Defining domestic water supply

In its Guidelines for Drinking-Water Quality, WHO defines domestic water as being '*water used for all usual domestic purposes including consumption, bathing and food preparation'* (WHO, 1993; 2002). This implies that the requirements with regard to the adequacy of water apply across all these uses and not solely in relation to consumption of water. The Guidelines exclude some specific uses (for instance dialysis and contact lens cleaning) and elevated requirements for some particularly sensitive sub-populations (for instance the severely immuno-compromised). Although this broad definition provides an overall framework for domestic water usage in the context of quality requirements, it is less useful when considering quantities required for domestic supply.

Sub-dividing uses of domestic water is useful in understanding minimum quantities of domestic water required and to inform management options. 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 updating the Drawers of Water study, Thompson *et al.* (2001) suggest a fourth category can be included of 'productive use' which was 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.

The first two categories identified by White *et al.* (1972): ‘consumption’ and ‘hygiene’, have direct consequences for health both in relation to physiological needs and in the control of diverse infectious and non-infectious water-related disease. The third category: ‘amenity’ may not directly affect health in many circumstances. 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).

The different primary uses of water are discussed in the following sections and the quantity requirement of each and its implication for health are reviewed.

3 Consumption

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 also essential for the preparation of foodstuffs and requirements for food preparation are included in the discussion of consumption requirements.

3.1 Basic hydration requirements

The human body requires a minimum intake of water in order to be able to sustain life before mild and then severe dehydration occurs. Adverse health effects have been noted from both mild and severe dehydration and the latter can be fatal.

The US National Institutes of Health (2002) provide a definition of mild dehydration as being a loss of 3-5% of body weight, moderate dehydration as being 6-10% loss of body weight and severe dehydration (classed as a medical emergency) 9-15% loss of body weight. In a recent review Kleiner (1999) defined mild dehydration as being the equivalent of 1-2% loss of body weight through fluid losses and over 2% loss as severe dehydration, whilst noting that there is no universally applied index of hydration status. Mild dehydration can be reversed by increased fluid intake and this may be enhanced through the use of salt replacement solutions. Severe dehydration will require rehydration strategies involving more than simple fluid replacement, and often food or other osmolar intake is needed; the process may take up to 24 hours (Kleiner, 1999).

Dehydration may be a short-term effect, for instance resulting from loss of body fluids in severe diarrhoea, which can be fatal. Short-term dehydration may also result from excess alcohol intake or increased water loss due to increased temperature and altitude or decreased relative humidity combined with inadequate fluid replacement. Dehydration may also be long-term (often mild) which may result in adverse health effects (Chan *et al.*, 2002; Kleiner, 1999). Long-term dehydration may result from inadequate fluid replacement, often as a consequence of depressed thirst mechanisms and perceptions of poor beverage taste.

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; urinary volumes exceeding 2 to 2.5 litres per day can prevent recurrence of stones in previously affected patients (Kleiner, 1999). White *et al* (1972) suggest that in order to reduce the risk of kidney stones, a minimum of 1.5 litres should be passed as urine each day.

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). Relative risks for men reduced to 0.46 for high volume water intake (5 or more glasses) and 0.54 for women who had medium intake (3-4 glasses) compared to low water intake (2 or less glasses). If it is assumed that each glass contained 0.25 litres (a reasonable estimate of size of glass) an estimate of a minimum of 1.25 litres per capita per day for men and 0.75 litres per capita per day for women is required to reduce risks of fatal coronary heart disease. Taking an average of these figures provides 1.0 litre per capita per day for a population-based estimate of the volume of water that reduces the risk of fatal coronary disease. Some studies have also indicated decreased risks of colonic and breast cancer with increasing fluid intake (Kleiner, 1999).

Kleiner (1999) notes that in general there is less available information regarding adverse effects on cognitive performance by dehydration, but highlights three studies suggesting that this would occur. A further review of literature indicated limited available studies in this area and somewhat contradictory evidence. In a study using volunteers, Neave *et al.*, (2001) found no significant main effects of hydration status on cognitive performance, whilst noting greater mood alertness after successive drinks. By contrast, Rogers *et al.* (2001) suggested that there was an immediate (although not sustained) improvement in cognitive performance on ingestion of water. This suggests that this area requires further investigation.

It is pertinent to note that the majority of health effects derived from dehydration are derived primarily from developed countries and there is very little available data from developing countries. However, although these impacts may represent an overall lower proportion of the burden is disease in developing countries, the effects from dehydration would not be expected to be different in developing counties.

3.2 Published Reference Values

In their review, 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 is lost through sensible perspiration if hard work is performed. These figures led them to suggest that a daily minimum of water required in tropical climates would be around 3 litres per person, although the volume of water loss suggests that this should be at the upper end of this scale. 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. However, they 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 rare cases, notably 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 in the USA, the average male should consume a minimum 2.9 litres per day and the average female 2.2 litres. Approximately one-third of this fluid was considered likely to be derived from food.

In the WHO Guidelines for Drinking-Water Quality, Guideline Values for chemical contaminants are based on the assumption of a 60 kg adult consuming 2 litres per day from drinking water, which would be equivalent to 3 litres per capita per day including food consumption (if the ratio cited by Kleiner were applied). Where specific guidance is needed for vulnerable populations, a figure of 1 litre per day for a 10kg child or 0.75 litre per day for a 5kg child are used (WHO, 1993; p31). The WHO-UNEP-ILO International Programme on Chemical Safety use reference values for volume of fluid intake in deriving its guidance, using reference body weights of 70kg for adult males, 58kg for adult females and an average of 64kg. The reference fluid intake values for these different reference body weights under different climatic and activity conditions are shown in table 1 below.

Table 1: Daily fluid intake reference values in litres per capita (IPCS, 1994)

	Normal conditions	**High average temp. 32°C**	**Moderate activity**
Adults	1.0-2.4, average 1.9 (including milk); 1.4 (excluding milk)	2.8-3.4	3.7
Adult male	2	-	-
Adult female	1.4	-	-
Child (10 years)	1.0	-	-

3.3 Specific population groups

Particular population groups have particular hydration requirements, including young children, pregnant or lactating women, the elderly, the terminally ill and athletes. Athletes are not discussed in this review as hydration would typically also include salt replacement and both the cause of dehydration and management of rehydration are more specialised than may legitimately be expected from a normal domestic supply.

As rehydration primarily relates to the replacement of lost fluid from natural processes, it is important to consider the losses of fluid from different age groups when considering vulnerable sub-populations. The losses of water from the bodies of small children are proportionally considerably greater than for adults, 15% of fluid per day as opposed to 4%. These proportionately higher losses explain why a 7kg child requires 1 litre per day fluid to replace lost fluid compared to 2.9 litres for a 70kg adult male, the increase in replacement fluid being a factor of three compared to a 10-fold difference in weight (Kleiner, 1999). Low-birth-weight infants need proportionally even greater fluid replacement per kilogram of weight than do other infants (Roy and Sinclair, 1975). The figures for fluid replacement exceed those for fluid intake noted above because this includes all forms of fluid used in hydration, approximately 30% of which will be derived from food rather than consumption of liquid.

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). In those groups with least access to water supply, women who are pregnant or lactating frequently continue to undertake at least moderate activity in high temperatures, therefore these needs are additive to the basic needs of all adults.

The elderly may not require additional volumes of water, but may be at greater risk from dehydration due to decreasing thirst sensations (Phillips *et al.*, 1984). Furthermore, studies have noted a relationship between age and the ability of the body to concentrate urine, suggesting an increasing water requirement to maintain good renal functioning (Rowe *et al.*, 1976).

For the terminally ill, Jackonen (1997) highlights a range of benefits and burdens related to dehydration, with benefits accrued from lower levels of distress and lower awareness of pain and reduced requirements for urination with the pain and discomfort that this may cause. Benefits of hydration include preventing dehydration and malnourishment as well as prolonging life and avoiding health problems such as renal failure. The benefits and burdens associated with dehydration amongst the terminally ill often relate to medical hydration (intravenous, nasogastric or nutrition administration) and therefore will have little impact on volumes of water required in a general domestic supply.

3.4 Requirements to maintain hydration

The evidence outlined above indicates that there are health concerns regarding hydration status and therefore the requirements for human to maintain an adequate hydration level and minimise risk of disease associated with adverse effects outlined above must be defined. The definition of the 'absolute minimum' quantity of water to sustain hydration remains elusive, as this is dependent on climate, activity level and diet.

In developing countries, White *et al.* (1972) and Gleick (1996) suggest that a minimum of 3 litres per capita per day is required for adults in most situations. However, households with least access to water supplies are more likely to be engaged in at least moderate activity and often in above-average temperatures. Data from the US Army reported in White *et al.* (1972) provides estimates of water quantity needs at different temperatures and activity levels. This indicates that at 25^{o}C with moderate activity in the sun (for instance agricultural work) approximately 4.5 litres are required to maintain hydration. This rises to about 6 litres at 30^{o}C or when hard work in the sun is undertaken at 25^{o}C. Although the US Army has more recent recommendations for hourly intake of water per hour in relation to heat categories and activity intensity to prevent heat injury, this do not easily translate into non-military activity. They do, however, stipulate that hourly fluid intake should not exceed 1.08 quarts (1.03 litres) and that daily intake should not exceed 12 quarts (11.35 litres) (United States Army Center for Health Promotion and Preventive Medicine, 2003).

The literature reviewed in section 3.2 to 3.4, indicates that the quantity of water required for hydration (whether via direct ingestion or food) should be a minimum of 2 litres for average adults in average conditions, rising to 4.5 litres per day under conditions typically facing the most vulnerable in tropical climates (see table 2 below) and higher in conditions of raised temperature and/or excessive physical activity. This figure can be interpreted as applying to all adults and to children, given the difficulty in determining whether the ration of adult/child water requirements would remain the same with increasing activity and/or temperature. These values encompass the range in which beneficial impacts on prevention of coronary disease and kidney stone occurrence appears likely and would be at the lower end of requirements to prevent recurrence of kidney stones.

By also taking into consideration the needs of lactating women, many of whom in the group with least access will still be expected to undertake moderate activity in high ambient temperatures, a minimum quantity required of fluid required for hydration (via both direct consumption and food) can be estimated as 5.5 litres per capita per day. This will not account for those in unusually hot environments or engaged in strenuous physical activity where minimum needs may be considerably greater.

As some hydration needs are met through fluid obtained from food, the figure of 5.5 could be interpreted in two ways. Firstly, it could be assumed that the water supply should be able to meet all hydration needs (i.e. minus contributions from food). The second approach would be to assume that one-third of all hydration fluid is derived from food and that therefore domestic water supply need only meet two-thirds of the minimum quantity identified.

In this report we use the former approach because as the proportion of fluid obtained from food may vary significantly in response to diet and culture from negligible to all hydration needs as noted by White *et al.* (1972). Therefore, trying to allocate a proportion of the fluid requirement to food on a global basis would risk significantly under-estimating water quantity needs in a number of situations where food contribution is negligible. As these are likely to be found in situations with vulnerable populations, notably in emergencies, this would entail a serious risk. Allocating the full hydration component to drinking water may over-estimate the quantity of water required, but this is believed to be no more significant that the variation likely to occur due to activity levels and temperature.

Table 2: Volumes of water required for hydration

	Volumes (litres/day)		
	Average conditions	**Manual labour in high temperatures**	**Total needs in pregnancy/lactation**
Female adults	2.2	4.5	4.8 (pregnancy) 5.5 (lactation)
Male adults	2.9	4.5	-
Children	1.0	4.5	-

3.5 Hydration needs: types of fluid intake required

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

Chan *et al.* (2002) demonstrated a statistically significant positive association between consumption of 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 interval 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. An attempt was made to identify the impact of specific fluids, but this was not possible for juices and sugared drinks because of generally low daily intake, the consumption of caffeinated beverages was positive but not statistically significant and the intake for soy milk was close to null. The authors note that the population studied consumed less alcohol and caffeine than the USA average which may limit the ability to project the findings more broadly. Although the analysis from this study does not support risk assessments of specific fluids, the study does highlight the specific value of water as opposed to more generic fluid intake.

3.6 Quality of water for consumption

The quality of water that is consumed is well-recognised as an important transmission route for infectious diarrhoeal and other diseases (WHO, 1993). The importance of water quality continues to be emphasised by its role in epidemics and contribution to endemic disease from pathogens (Ford, 1999; Payment and Hunter, 2001). This affects both developed and developing countries, although the majority of the health burden is carried by children in developing countries (Prüss *et al.*, 2002; WHO, 2000). However, recent outbreaks such as that of cryptosporidiosis in Milwaukee and *E.coli* O157:H7 and *Campylobacter jejuni* in Walkerton, Ontario illustrate that the developed world also remains at risk (Mackenzie *et al.*, 1994; O'Connor, 2002).

Disease may also result from consumption of water containing toxic levels of chemicals. The health burden is most significant for two chemicals: arsenic and fluoride. Arsenic contamination of drinking water sources is being found in increasing numbers of water supplies world-wide and in Asia in particular. The total disease burden is as yet unknown, but in Bangladesh, the country with the most widely reported problem, between 35 and 77 million people are at potential risk (Smith *et al.*, 2000). Fluoride is also a significant global problem and WHO (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 although there remains uncertainty about the scale of adverse health effects from nitrate as few countries include methemaglobinaemia as a notifiable disease (Saywell, 1999). Raised nitrate is, however, identified as a potential public health problems in countries where concentrations in groundwater reach extremely high values (Melian *et al.*, 1997).

Water provided for direct consumption and ingestion via food should be of a quality that does not represent a significant risk to human health. A 'zero-risk' scenario for public supplies is not achievable and evidence points to the need to define tolerable risks, commonly based on estimates of numbers of excess cases per defined population size . This approach underpins much risk assessment thinking within the water sector for both microbial and chemical contaminants (Fewtrell and Bartram, 2001; Haas *et al.*, 1999; WHO, 1996).

3.7 Quantities of water required for cooking

Water is essential as a medium for preparing food. One study noted that the volume of cooking water available may be an important determinant for diarrhoea incidence in children over 3 years of age, although this was less important than water quality for the under 3 years age group (Herbert, 1985).

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 for the average family to provide nutritional benefit.

It is difficult to be precise about volumes required to prepare staples as this depends on the staple itself. However, an example can be provided for rice, which probably represents the most widely used staple food worldwide. Recommendations for nutrition usually deal with the intake of nutrients rather than specific food stuffs. Most food pyramids give a suggest an intake for cereals of 6 to 11 servings per day, or 600 – 1100 grams per day (Graeme Clugston, personal communication). To prepare rice using the adsorption method (i.e. only sufficient water to cook the rice is added), 1.6 litres is required for 600g per capita per day.

More water may be required to ensure that other foodstuffs can be cooked, although defining minimum quantities is difficult as this depends on the nature of the food being prepared. For instance, Gleick (1996) suggests that on average 10 litres per capita per day is required for food preparation, whilst Thompson *et al.* (2001) show that in East Africa only 4.2 litres per capita per day were used for both drinking and cooking for households with a piped connection and even less (3.8 litres per capita per day) for households without a connection. Taking into account drinking needs, this suggests that between 1.5 and 2 litres per capita per day is used for cooking.

If the quantity of water required for cooking rice is taken as representing the needs for staple preparation and assuming further water is required for preparation of other food, the evidence suggests that in most cases approximately 2 litres per capita per day should be available from domestic supplies to support food preparation.

By adding the volume required for food preparation to the volumes identified in table 2, a figure for total consumption (i.e. drinking water plus water for foodstuffs preparation) of 7.5 litres per capita per day can be calculated as the basic minimum of water required, taking into account the needs of lactating women.

4 Water quantity requirements for hygiene

The need for domestic water supplies for basic health protection exceeds the minimum required for consumption (drinking and cooking). Additional volumes are required for maintaining food and personal hygiene through hand and food washing, bathing and laundry. Poor hygiene may in part be caused by a lack of sufficient quantity of domestic water supply (Cairncross and Feachem, 1993). The diseases linked to poor hygiene include diarrhoeal and other diseases transmitted through the faecal-oral route; skin and eye diseases, in particular trachoma and diseases related to infestations, for instance louse and tick-borne typhus (Bradley, 1977; Cairncross and Feachem, 1993).

The relative influence of consumption of contaminated water, poor hygiene and lack of sanitation on diarrhoeal disease in particular has been the topic of significant discussion (see for example 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. The desire for evidence-based health interventions is driven by the need to maximise benefits from limited resources (a critical factor both for governments and their populations). It is also driven by the desire to ensure that populations benefit from the interventions that deliver the greatest improvement in their health.

4.1 The links between water supply, hygiene and disease

Classifying diseases by causative agent such as microbe type for infectious disease has a value in terms of understanding aetiology of infection. However, a more effective way to inform decision-making is to categorise pathogens /diseases in relation to the broad mode of transmission. Bradley (1977) suggests that there are four principal categories that relate to water and which are not mutually exclusive:

- water-borne - caused through consumption of contaminated water (for instance diarrhoeal diseases, infectious hepatitis, typhoid, guinea worm);
- water-washed - caused through the use of inadequate volumes for personal hygiene (for instance diarrhoeal disease, infectious hepatitis, typhoid, trachoma, skin and eye infections);
- water-based - where an intermediate aquatic host is required (for instance guinea worm, schistosomiasis); and,
- water-related vector - spread through insect vectors associated with water (for instance malaria, dengue fever).

Other workers have suggested a change in this classification system to replace the waterborne category with faecal-oral (to reflect multiple routes of transmission) and to restrict the water-washed diseases to only as those skin and eye infections that solely relate to the quantity of water used for hygiene (Cairncross and Feachem, 1993). The original Bradley (1977) system has particular value as its focus is on the potential impact of different interventions. The occurrence of particular diseases in more than one group is a legitimate outcome where distinct interventions may contribute to control. Thus guinea worm for example is classified as both a water-based disease and water-borne disease.

4.2 Relationships between water, sanitation hygiene and diarrhoea

Diseases primarily transmitted through the faecal-oral route (shown in figure 1 below) include infectious diarrhoea, typhoid, cholera and infectious hepatitis. Faecal-oral diseases are associated with acute symptoms (with a probability of death) and in some cases with delayed sequelae. Transmission may occur through a variety of mechanisms, including consumption of contaminated water and food as well as through person-person contact (Bradley, 1977). These are dealt with together here, in order to emphasise the importance of local disease patterns rather than applying generic models. 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. As noted by Vanderslice and Briscoe (1995) as all the interventions deliver some improvement, the relative impacts of each may have limited relevance for policy.

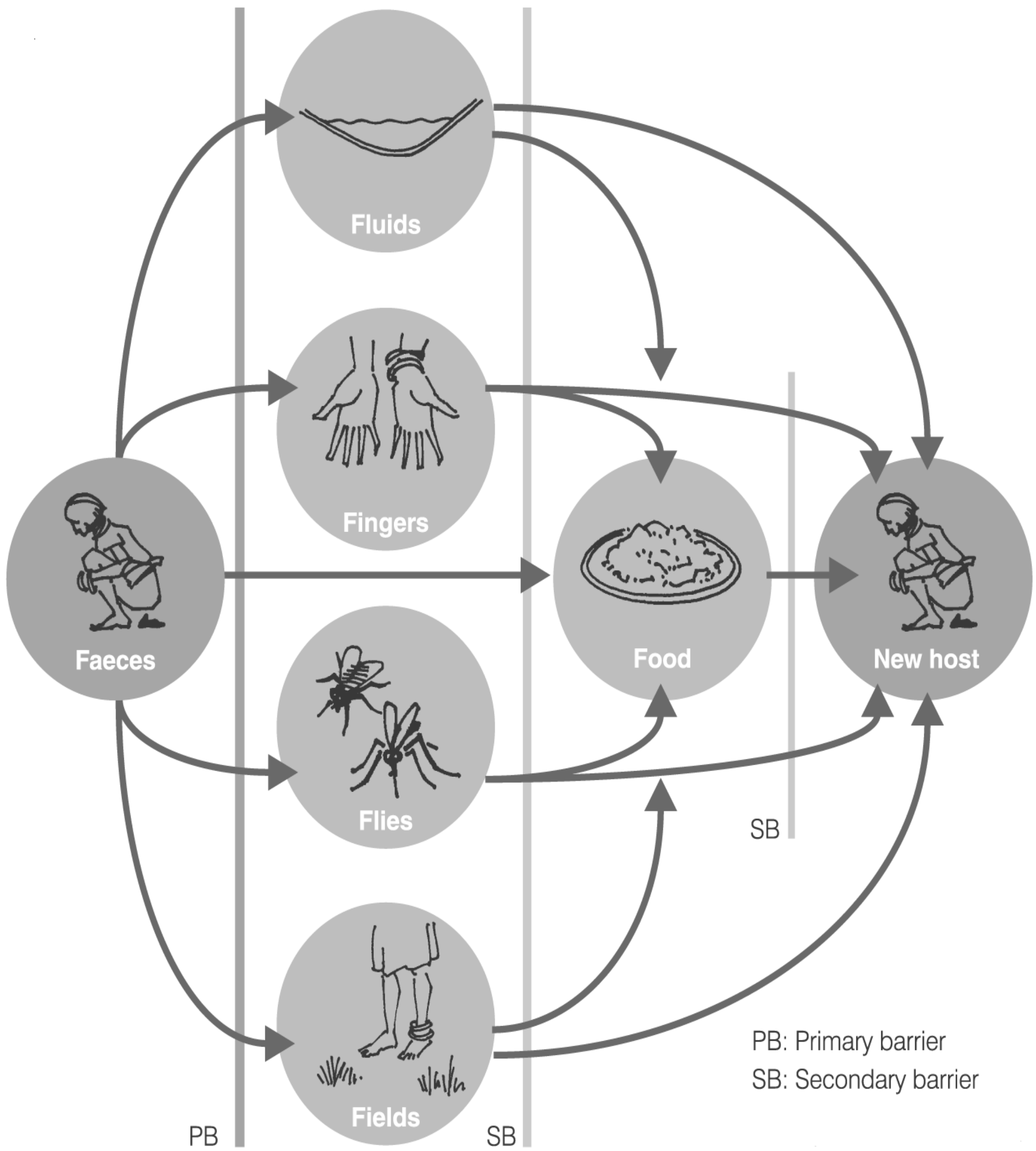

Figure 1.1: Faecal-oral route transmission of disease (taken from WELL, 1998)

Other factors apart from water and sanitation facilities and hygiene behaviours may significantly influence diarrhoeal disease. For example breast-feeding has been noted in several studies as being protective against diarrhoeal disease independently of other interventions (Al-Ali *et al.*, 1997; Vanderslice and Briscoe, 1995).

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 estimated. 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 summarised below in table 3 and suggest that median reductions in diarrhoeal disease from water availability were higher than those recorded for water quality improvements. Combined improvements in quality and availability led to greater median reductions in disease incidence. 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 3: Percentage reductions in diarrhoeal disease rates attributed to water or excreta disposal improvements (Esrey *et al.*, 1985)

Type of intervention	Number of studies	Percentage reduction	
		Median	Range
All interventions	63	22	0-100
Improvements in water quality	9	16	0-90
Improvements in water availability	17	25	0-100
Improvements in water quality & availability	8	37	0-82
Improvements in excreta disposal	10	22	0-48

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 4. The data from the rigorous studies suggested that median reductions in morbidity were relatively low from all water improvements, unless these were combined with sanitation improvement. In this review, the impact of combined improvements in water quality and quantity resulted in a lower reductions than for water quantity interventions alone, which is counter-intuitive and contradicts the findings of the previous review. The authors of this study also noted that the benefits derived from increased water availability were not necessarily felt in all age groups, a finding highlighted in a previous study by Herbert (1985).

Table 4: Reduction in diarrhoeal disease morbidity in one or more components of water and sanitation (Esrey *et al.*, 1991)

Factor	All studies		Rigorous studies	
	N	**Median % reduction**	***N***	**Median % reduction**
Water and sanitation	7	20	2	30
Sanitation	11	22	5	36
Water quality and quantity	22	16	2	17
Water quality	7	17	4	15
Water quantity	7	27	5	20
Hygiene	6	33	6	33

These findings are most readily understood as demonstrating the significant impact of all interventions and that the scale and relative impact of a single intervention depends strongly on the dominant route of exposure under local circumstances. 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. Sazawal *et al.*(1991) demonstrated that children with persistent diarrhoea have an overall higher number of episodes of diarrhoeal disease, compared to those suffering from acute diarrhoea. Persistent diarrhoea will affect immune competency and increase subsequent susceptibility. Therefore, in understanding local disease patterns, identifying whether a significant proportion of children suffer from persistent diarrhoea may be important in understanding exposure routes.

A variety of 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. In the Philippines, increasing risks of hospitalisation due to severe diarrhoea was 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 (Baltazar *et al.*, 1993). Bukenya and Nwokolo (1991) showed that the presence of a standpipe at households in urban Papua New Guinea was associated with less diarrhoea than users of communal sources and that this was found across all socio-economic groups, whilst noting the importance of removal of both human and pig faeces. Gorter *et al.* (1991) showed that in Nicaragua, that children living in households with a water supply within 500m had 34% less diarrhoea than children living in households whose water source was over 500m from the house. Gorter *et al.* (1991) note there once a water supply is within 500m, reducing distance had no further impact.

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, 1985). A previous study in rural Lesotho, height for weight scores were found to be better associated with latrine use than water quantity, water quality not being analysed as it had previously been found to be insignificant (Esrey *et al.*, 1992). However, in South India, defecation practice was not a significant predictor of height for weight scores (Herbert, 1985).

A recent study in Pakistan demonstrated that increased quantities of water available at households was critical in preventing stunting (van der Hoek *et al.*, 2002). This study showed that the presence of storage containers linked to household connections was the most protective level of service and that limited benefits were accrued when water was only available via a yard tap compared to collection from a communal source.

The evidence from the literature suggests that water availability has an important influence of health and diarrhoea incidence in particular, although as noted by both Esrey *et al.* (1991) and Herbert (1985) 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 better quality of water supplied (Esrey, 1996). There appears to be limited 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. In the study reported by Gorter *et al.* (1991), although not explicitly stated, there is an implication that all water sources when within 500m offered health benefits as no difference was noted in diarrhoeal disease incidence between water sources.

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 take 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 commentaries suggest that reductions in diarrhoeal disease with increased service level may in fact be much more modest (Vanderslice and Briscoe, 1995).

Despite the evidence pointing to the benefits of increased quantities of water on health, the relationship 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 Huttly *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, with a range of 30-89%. Recent work appears to indicate that the median reduction may in fact be higher, although the results remain to be published (Val Curtis, personal communication). It should be noted that the figures quoted by Huttly *et al*. (1997) are of a similar order of magnitude to estimates of disease reduction using household treatment of water (Sobsey, 2002). This indicates that household-targeted interventions deliver significant improvements in health even when environmental conditions and services are not conducive to improved health, although as with all environmental interventions the range of impacts is considerable. In the case of household water treatment, this appears to be from zero reduction in diarrhoea incidence to about 20% reduction.

The timing of handwashing maybe important. Experience suggests that the most critical times are following defecation and before eating. 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 *e*t al., 1997). Stanton and Clemens (1987) found reduction in diarrhoea incidence among young children was influenced by maternal hand washing prior to food preparation.

A number of studies suggest that handwashing with soap is the critical component of this behaviour and that handwashing only with water provides little or no benefit (Cairncross, 1993; Ghosh *et al.*, 1997; Khan, 1982; Oo *et al.*, 2000). Hoque and Briend (1991) showed that whilst less effective than when using a rubbing agent, such as soap, mud or ash, some reductions in contamination were found when washing with water alone, but that use of alternative rubbing agents (mud or ash) provided the same benefits as soap. Hoque *et al.* (1995) also found that use of mud, ash and soap all achieved the same level of cleanliness with hand washing. and suggest that it is the action of rubbing of hands that was more important than the agent used. These authors suggest that rinsing with 2 litres of clean water was also protective, although this seems to be a large quantity, which would difficult to sustain in the absence of on-plot access to water.

In a study in Peru, 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. The exact nature of the water supply is unclear, but appears to have been concrete tanks at households that were periodically filled, either from tanker trucks or piped water. The authors of this study concluded that hygiene education was of limited value unless water supplies were improved.

4.3 Relationships between water, hygiene and other infectious diseases

Infectious diseases of the skin (a sub-set of water-washed diseases) and trachoma are amongst the diseases on which water quantity would be expected to exert significant influence. Trachoma is the most extensively studied disease, given its relatively high impact on health.

In a review of available evidence, Prüss and Mariotti (2000) found that only two studies out the 19 reviewed showed a significant relationship with water quantity and suggested that the relationship between trachoma incidence and quantity of water was not simple. One 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 another study from 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). Such volumes of water are indicative of water piped into the home. Prüss and Mariotti (2000) also note six studies that showed a positive relationship between increased access to water and reduced incidence of trachoma, with a median reduction of 27%, with a range of 11-83% reduction.

In most studies, distance from primary water source to home 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 associated with significant differences in incidence were again relatively gross 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 away.

Only in one study was there a more sensitive measure, the difference being between sources more than or less than 200m distant. All these studies were included within the review by Prüss and Mariotti (2000) and were in the group of six studies showing a reduction in trachoma incidence with increased access.

The reviews by Esrey *et al.* (1991) and Prüss and Mariotti (2000) provide evidence to indicate that only relatively gross differences in water quantity, as indexed by access by service level, are significant in relation to the incidence of trachoma. The importance of distance is supported by several other studies and reviews on trachoma prevalence (Hsieh *et al.*, 2000; Prost and Négrel, 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 were associated with trachoma, but total per capita volume use was not. Several workers have suggested that it is value placed on the use of water for hygiene rather than source proximity and per capita water collection, which is protective 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, clustering of cases within communities is noted as important, as is the presence of siblings with trachoma within individual households (West *et al.*, 1991; 1996). Research suggests that factors such as cattle ownership are also important in rural areas and that sanitation and garbage disposal are important in both urban and rural areas (Hsieh *et al.*, 2000; West *et al.*, 1996; Zerihun, 1997). This is supported by a review of the evidence to support environmental and facial cleanliness interventions in integarated trachoma programmes (Emerson *et al.*, 2000).

Infectious skin diseases have been less well researched. In a review of influences on skin disease in rural Tanzania, Gibbs (1996) found that household density and low socio-economic conditions were important determinants 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 20 minutes and the other having a water source that was 46 minutes from the village. Using figure 2, this would suggest a significant difference in quantities of water collected.

Evidence from Nepal suggests that the influence of water on hygiene may also reflect the availability of heated water rather than all water in cold climates. A review of water supply access data and diarrhoeal and skin diseases showed that in Districts which have typically very cold seasons for part of the year, hygiene-related diseases remain much higher than average (Howard and Pond, 2002). It is suggested that despite increasing access to water supply and sanitation, the absence of hot water inhibits good hygiene, a finding in line with research into emergency responses in countries with distinct cold seasons (Buttle and Smith, 1999).

4.4 Minimum quantity of water required for effective hygiene

The evidence from the literature consistently points to use of water as being important to controlling disease and the fact that lack of access to water may impede its use and thereby adversely affect health. The evidence indicates that the benefit from increased quantity of water would only be felt in relation to the gross differences of service level and that hygiene behaviour is more important within populations using communal water sources. This suggests that incremental benefits among households with a communal source of water from increased quantities of water used are limited.

Review of the data regarding hygiene practices and disease therefore does not enable the definition of a minimum quantity of water recommended for use to ensure effective hygiene is practised. The evidence suggests that while benefits are accrued from increased availability of water, this is not solely related to quantities of water used, although increased availability is likely to increase quantities used. The evidence further suggests that it is the effective use of both water and cleansing agents and the timing of hygiene practices that are more important than volumes of water used. Furthermore, as some hygiene behaviour protective of health, for example laundry and bathing, may be carried out off-plot, the quantity of water required to sustain good hygiene may vary significantly with water collection behaviour.

For water quantity to act as an absolute constraint on hygiene, it must be available only in very small quantities. To act as a positive driver for improved hygiene, water must be available at higher service levels and ideally supplied at least through one tap on the house plot. Since (as discussed below), the quantity of water collected may be relatively inflexible beyond gross differences in supply type/service level defining a minimum quantity of water is neither supported by evidence nor of practical value.

4.5 Water quantity/access and non-infectious disease

There are other health benefits of increased access within the range implying physical collection, notably reduced potential for damage to the spine and for the early onset arthritic diseases and protection against hip damage (Dufault, 1988; Page, 1996). Where women must walk long distances this may exacerbate malnourishment and also affect the quantity and quality of milk produced by lactating women (Dufault, 1988).

4.6 Quantity and accessibility: how much do people use and what are the links?

The importance of water availability has been shown above to influence health in the preceding discussion (sections 3 and 4) and some of the difficulties in interpreting available data have been noted. . As noted in section 4.4, the benefit from increased quantity of water is only felt in relation to the gross differences of service level. It is therefore useful to review the evidence of the interaction between accessibility and quantity in order to assess how health may be influenced by these factors.

Most of the studies cited in the above-mentioned reviews as providing evidence of the greater importance of quantity actually provided measures of accessibility, with the assumption that increased accessibility equates to increased volumes of water used (Esrey *et al.*, 1991). It is therefore important to assess to what extent this relationship is true and what changes in quantity can be expected. This has particular value in ensuring that the formulation of the true nature of the problem is correct in order to inform effective decision making.

Cairncross (1987) provides an example from Mozambique that demonstrated that water consumption in a village with a standpipe within 15 minutes was 12.30 litres per capita per day compared 3.24 litres per capita per day in a village where it took over five hours to collect a bucket of water. The excess water was primarily used for hygiene-related purposes. However, the difference in time points to the influence of only gross differences in service level, in this case between effectively no access and a service level that can be described as basic access. Reviewing several studies on water use and collection behaviour, Cairncross (1987) suggests that there is a clearly defined general response of water volumes used by households to accessibility, shown in figure 2 below.

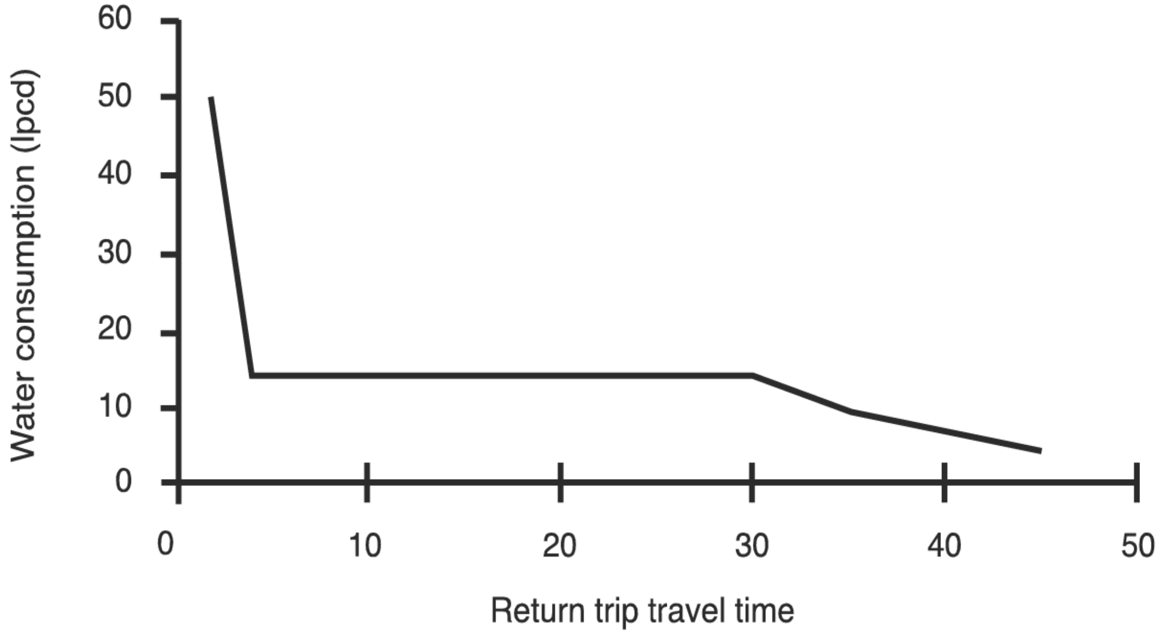

Figure 2.2: Graph of travel time (in minutes) versus consumption (taken from WELL, 1998)

Once the time taken to collect water source exceeds a few minutes (typically around 5 minutes or 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 around 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, in rural areas to a bare minimum where only consumption needs can be met. In urban areas, where water supplies may be close but total collection times are very high, greater volumes may be collected that will support hygiene, although the overall impact on household poverty is significant (Aiga and Umenai, 2002).

Once water is delivered through at least a single tap on-plot, the quantity of water increases significantly and further increases are found 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 5 below illustrates 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 outside the home, average consumption drops still further to roughly one-third the average consumption at a yard tap and one-tenth that of households with water piped into the home.

Table 5: Average water consumption figures, Jinja, Uganda (WELL, 1998)

Type of supply	Average consumption (l/c/d)	Service level
Traditional sources, springs or handpumps	15.8	Communal
Standpost	15.5	Communal
Yard tap	50	In compound
House connection	155	Within house (multiple)

The available evidence suggests that the volume of water used in the home is sensitive only to gross differences in service level. As noted by WELL (1998) therefore the first priority is to ensure that households reach the plateau (figure 3), that is to have access to an improved water source within one kilometre, which corresponds to the current definition of reasonable access used in assessing progress in global coverage with water supply and sanitation (WHO and UNICEF, 2000). Beyond this, unless water is provided at a household level, no significant changes in water quantities collected will be noted. Clearly benefits at each stage are also accrued from ensuring that the water is of a quality consistent with a tolerable risk to health and from ensuring that the water collected is put to effective use for hygiene.

Although there are limited published studies, there appears to be relatively little variation in quantities used when the water is supplied through a yard level of service, probably because this level of service does not permit easy use of water-hungry devices and efforts expended to obtain water remain sufficiently high to limit overall quantities used. Once water is supplied through multiple taps within the house, there is more significant variation in volumes used as more water-hungry and time-saving devices can be deployed and physical effort to obtain water is largely obviated.

Studies in Kenya, Tanzania and Uganda 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). For houses using water sources outside the home, an average of 6.6 litres per capita are used for washing dishes and clothes and 7.3 litres per capita for bathing. By contrast for houses with a household 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. The authors suggest that for the households using a water source outside the home, the lesser volume collected has a negative impact on hygiene although this is not quantified.

4.7 Quantity and cost: what influence does this have on use?

There have also been suggestions that where water is purchased, the cost may also be a limiting factor on the volumes of water used. The literature is, however, more limited than that dealing with the influence of distance. There are suggestions that in some environments a graph of similar dimensions and shape as the quantity-distance graph can be developed (Cairncross and Feachem, 1993; WELL, 1998).

Cairncross and Kinnear (1992) showed that the cost of water purchased from vendors in Khartoum, Sudan, did not led to a significant reduction in the quantity of water procured. Cairncross and Kinnear (1992) suggested that in poorer communities, where an increasing proportion of household income must be spent on acquiring water, the only major item of expenditure available for sacrifice was the food budget and therefore it was probable that high costs of water were contributing to under-nutrition.

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 over the preceding 30 years by 20% (when compared to the study by White *et al.* (1972)). Thompson *et al*. (2001) also note that average costs of water used by households without a household connection in rural and urban areas increased by 14% and 28% respectively. At the same time, households with connections to piped water decreased water consumption by 50%, while urban and rural households using off-plot water sources actually increased consumption by 60% and 80% respectively.

The overall impact of changes in cost on volumes of water collected does not seem to have been significant and may be confounded by other factors. The authors note that the reduction in use by households with a connection to a piped supply may be as a result of a number of factors, including increasing intermittence of piped supplies. A further issue not discussed that may have influenced quantities used is the expansion in the use of meters leading to more careful consumption by households. For households lacking a household connection, cost increases may have been off-set by increasing household incomes, allowing greater quantities of water to be purchased.

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. This showed a marked change from the first study of water use behaviour in East Africa where container size and source location were the most important factors. For households with a connection to the piped water supply, consumption was again noted as being primarily determined by wealth indicators. In other settings, the increasing use of metering in piped water supplies may influence consumption and the use of progressive tariffs can be applied to penalise excessive use, whilst promoting provision of quantities to meet basic hygiene needs.

In studies on water usage undertaken in three urban areas in Uganda (Howard *et al.*, 2002) there was limited evidence of a significant association between cost of water and quantities of water collected. In one town, Soroti, quantities of water were actually greater from sources where payment was required, although as these were taps supplied to a compound, this is likely to have been a function of access (Howard, 2002). The major influence of the need to purchase water appears to have been to promote multiple source use, thus elasticity was seen primarily in source selection behaviour rather than reducing volumes or changes in prices.

4.8 Other factors that may affect quantities of water used

Factors such as supply reliability may also influence quantities of water collected, although again there is very limited published data to establish what relationships exist. Zerah (2000) indicates that low-income families in New Delhi are likely to be at greatest risk from poor water supply continuity. As they have more limited resources, they are 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 is not quantified. 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. The greatest problems may be felt when discontinuity is frequent, but very unpredictable. Anecdotal evidence from many African cities indicate that this is common and may lead to collection of water from piped networks at odd hours, including late at night.

When investigating consumption patterns within a piped water supply with multiple levels of service, the interaction between the volumes used between different levels of service requires attention. Volumes of water available for users of lower service levels may be reduced as a direct consequence of over-consumption by households with higher-service levels. This has been shown in a study in Ghana, where low-income communities that relied on public taps received less water and faced greater shortages than high-income communities in part because of the consumption patterns of the latter (Stephens, 1996).

A further problem with intermittent water supply is that households may be forced to store water within or close to the home, thus leading to increasing risks from vector-borne diseases such as dengue fever (Ahmad, 2000; Ault, 1994; Rosenbaum *et al.*, 1995). Similar problems will also noted in houses that only have access to a basic level of service, where water storage is required.

4.9 Laundry: on and off-plot use

Minimum requirements for domestic supply should include adequate water for laundry and bathing. In some cases this will be done at the house and in other circumstances some or all of these activities may be carried out at the water source rather than at the household. In both cases, it would be expected that if an improved source is used, this should provide adequate quantities of water to meet these demands.

Where the source is an improved communal source whether laundering occurs at the house or source may vary on the nature of the settlement, with greater use at the household expected in urban areas. For instance, a significant proportion of households in urban Uganda appeared to collect and carry water back to the home for laundering (Howard *et al.*, 2002). In rural areas, it may be socially acceptable for people to bathe and launder clothes at or close to the water source. In some cases, designs for water supplies include facilities for bathing and laundry.

In some communities, users of communal supplies may be reluctant to transport sufficient water for laundry and may opt for use of alternative sources. In some communities it has been noted that the use of water from different source types may vary depending on judgements made as to the acceptability of the source for a given use (Madanat and Humplick, 1993). The term ‘rationality factor’ has been used to describe this differential use of water from different sources in rural areas (Almedom and Odhiambo, 1994). For instance, in East Africa it was noted that 30% of the population without household connections to a piped water supply use unprotected water sources for laundry (Thompson *et al.*, 2001). This may increase risks to health, for instance by increasing exposure to water-based and vector-borne diseases such as schistosomiasis and potentially other vector-borne diseases.

Where water is scarce or beyond the threshold of 1000m, there may be water source or time constraints that limit the potential for laundering and bathing at source or transporting water home. As a result, the frequency of bathing and laundering may reduce, thus potentially increasing the risks of some infectious diseases (Thompson *et al.*, 2001).

4.10 Minimum requirements for all hygiene needs

The evidence suggests that water quantities used by households are primarily dependent on access as determined by distance and/or time for collection. These differences are primarily seen as functioning at four levels, broadly equivalent to service level, shown in table 6 below. The estimated quantities of water at each level may reduce where water supplies are intermittent and the risks of ingress of contaminated water into domestic water supplies will increase.

Table 6: Service level descriptors of water in relation to hygiene

Service level description	**Distance/time measure**	**Likely quantities collected**	**Level of health concern**
No access	More than 1000m or 30 minutes total collection time.	Very low (often less than 5 l/c/d).	Very high as hygiene not assured and consumption needs may be at risk. Quality difficult to assure; emphasis on effective use and water handling hygiene.
Basic access	Between 100 and 1000m (5 to 30 minutes total collection time).	Low. Average is unlikely to exceed 20 l/c/d; laundry and/or bathing may occur at water source with additional volumes of water.	Medium. Not all requirements may be met. Quality difficult to assure.
Intermediate access	On-plot, (e.g. single tap in house or yard).	Medium, likely to be around 50 l/c/d, higher volumes unlikely as energy/time requirements still significant.	Low. Most basic hygiene and consumption needs met. Bathing and laundry possible on-site, which may increase frequency of laundering. Issues of effective use still important. Quality more readily assured.
Optimal access	Water is piped into the home through multiple taps.	Varies significantly but likely above 100 l/c/d and may be up to 300l/c/d.	Very low. All uses can be met, quality readily assured..

These levels of access can also be interpreted in terms of household water security. The no access group effectively have no household water security as the quantities collected are low, the effort taken to acquire water is excessive and quality cannot be assured. The group with basic access could be said to also have basic household water security, provided that water is (reasonably) continuous and quality can be assured at source and protected during subsequent handling.

The group with intermediate access can be said to have effective household water security as sufficient water is available to meet domestic needs and quality can be assured. This may be influenced by the degree of discontinuity within the supply, but it would be expected that household coping strategies would include bulk storage, which has been shown to be protective of health in Pakistan (van der Hoek e*t al.*, 2002). The group with optimal access also have optimal household water security with quantity, quality and continuity all likely to be adequate for domestic water needs.

The available data indicates that service level is more relevant to health than quantity of water and provides an indication of the volume of water that is available and used by households. The level of basic access is broadly equivalent to current definitions of minimum quantities are water required for health (WELL, 1998) and intermediate access equivalent to quantity of water that Gleick (1996) argued was the basic water requirement. In relation to cost, the evidence available remains limited and contradictory, as does the evidence for relationships between reliability and quantity of water. However, it is likely that both will influence quantities of water collected in some settings and further research is required in this area.

Available evidence suggests that health is significantly compromised at service levels described as ‘no access’ in table 6 where volumes collected may barely exceed the minimum for hydration. Estimates suggest that of the global population estimated in 2000 of 6 billion people, around 1.1 billion are in a situation categorised as ‘no access’ within this paper.
Whilst significant health gains accrue to those 4.9 billion benefiting from ‘basic access’ significant health gains continue across categories ‘intermediate access’ and ‘optimal access’. Approximately 2.8 billion of the global population presently have a household connection to a water supply, which covers both the category of intermediate and optimal access.

A minimum for basic health protection corresponds to ‘basic access’ and experience shows that this is equivalent to a water collection of less than 20 l/c/d, of which about 7.5 litres is required for consumption. The effective use in hygiene practices of the limited water available at basic access service level is important if available health benefits are to accrue. The basic level of supply should be regarded as a minimum quantity of water and attention paid to increasing levels of service to yard level in order to increase volumes of water collected.

5 Other Uses of water and links to quantity

5.1 Household productive uses of domestic water

This section deals with the productive uses of domestic water at a household level, which includes brewing, small-scale food production and household construction in low-income areas. We do not consider community-level enterprises that use water resources in income-generating activities, such as irrigation systems (beyond simple use of water by a household for gardening), industry, larger commercial entities, energy production and transport. However, as noted in the introduction, in terms of overall use of water sources the economic use of water typically greatly exceeds that used for domestic supply, but may compromise the ability of the resource to meet basic needs (either through over-consumption or through uses leading to quality deterioration).

The health sector oversight of water supply, has traditionally not considered productive uses of water as important to control. However, it is increasingly recognised that productive uses of water have particular value for low-income households and communities and have health and well-being benefits (Thompson *et al.*, 2001). Direct health benefits are derived for example from improved nutrition and food security from gardens crops that have been watered. Indirect health benefits arise from improvements in household wealth from productive activity. In urban areas, this often is essential for low-income communities to meet nutritional requirements and may offer additional income from small-scale sales.

Fass (1993) notes that in families living in 'ultra-poverty' water could form anywhere between 1.5 and 10% of the total production costs in household enterprises. The removal of a water supply, or deterioration in the quality of service, through decreased quantity or availability or increased intermittence or cost may lead to further poverty among poor households using this water for small-scale economic activities such as food production. The quality of water used for productive processes needs to be suitable for domestic supply where it is used for processing food for retail or in some circumstances irrigation for its production.

5.2 Amenity uses of water

Amenity uses are not typically considered in relation to health aspects of water quantity. Amenity uses include lawn-watering and car washing, although in some cases the latter would be more correctly categorised as productive uses of water as it may be used to provide an income. There are some benefits of purely amenity uses of water in terms of quality of life. However, particularly for the most vulnerable, amenity use of water is likely to be limited.

The principal concern in relation to amenity uses of domestic water supplies is to reduce the consumption of water for these purposes when this may place a significant demand on the water supply such that universal basic access is compromised. This is a problem noted in many developed countries where increasing efforts are being made to educate users on the problems of use of water for such purposes and in some cases restrictions applied and enforced to conserve water resources. Such approaches may include the use of variable tariff rates that penalise excess use, although in this case care must be taken to ensure that there would be no financial penalty for ensuring water for basic needs, including laundry.

Over-use of scarce water supplies for amenity uses is also found in developing countries, particularly in urban areas where the patterns of use among the wealthy may directly impact on the availability of water to the poor (Stephens, 1996). Therefore controlling amenity use of domestic water supplies should be driven to ensure that basic needs are met throughout the population in an equitable manner. It is important that such controls consider not only meeting the basic needs for current populations, but also takes into account future population growth. Furthermore, as many developing countries are either already experiencing or facing water scarcity and water stress, the need to control consumption of water to conserve resources is also critical (Gleick, 1993).

6 Implications

The evidence reviewed and conclusions drawn have significant implications regarding the development and application of norms for water quantity. This includes advocacy for access not quantity, the monitoring and evaluation with progress in meeting international and national goals for water supply, prioritising interventions and applications within specific contexts, such as emergencies.

6.1 Changing the nature of the debate: household water security/access not quantity

The available evidence indicates that the quantity of water that households collect and use is primarily dependent on accessibility (as determined by both distance and time). There is some indication that cost and reliability may also influence quantity of water collected, although the available evidence is limited and often contradictory.

The influence of accessibility operates as a function of service level, which can be divided into the five categories shown table 6 above. It is therefore logical that the debate regarding quantity is not related to volumes of water available but by the level of service provided. Increases in quantities of water used will only be achieved through upgrading of service level. Furthermore household water security improves with increasing service level, which will contribute to reducing poverty.

The first priority for interventions to improve access to water supplies is to ensure that at least basic access is achieved. At a basic level of service the volume of water collected is likely to be around 20 litres per capita per day. There is no evidence that behaviour change interventions have been successful in promoting increases in water quantities used in households that have achieved basic access to improved water supply. At this level of service, it is the effective use of the available water that is of principal importance, including the importance and timing of hand and face-washing and household water treatment, in controlling infectious disease transmission. Once this level of access is achieved, attention should be placed on providing guidance and support in hygiene practices and water quality management techniques that will reduce the risk of diarrhoeal disease transmission.

Notwithstanding the emphasis on personal hygiene, further health gains are typically associated with increasing levels of service - especially in upgrading to an ‘on plot’ level of access and to a lesser extent when upgrading from this level to ‘multiple tap in house’. Provision of ‘intermediate access’ levels of service will result in the use of approximately 50 litres of water per capita per day. ‘Optimal access’ will result in much higher quantities of water being consumed and the emphasis may change to restriction on quantity used. Upgrading to these levels of service therefore represent successive priorities, once basic access is achieved.

Overall, many of the health benefits ultimately accrue from proper water usage and good hygiene behaviours and simple provision of infrastructure alone is unlikely to maximise health gains. Poor hand-washing practice has been reported in countries with abundant in-house water supplies and general availability of soap and interventions to improve hygiene will usually provide some improvements in health in any setting, irrespective of socio-economic conditions or service level.

In many developing countries, the challenge remains to improve overall system management to reduce intermittence, make costs of water affordable and to develop incentives for users to be willing to obtain a legal connection and to (Howard, 2001; Sansom *et al.*, 2000; WELL, 1998; World Bank, 1993). It may also require rethinking how services can be delivered to the urban poor in particular and developing approaches to offering a range of technical options to communities, community management and more effective financing of sector improvements (Briscoe, 1996; Cotton and Tayler, 1994; Howard, 2001; Subramanian *et al.*, 1997; World Bank, 1993).

6.2 International Development Targets

The UN (2000) set a Millennium Development Goal to *'halve the proportion of people who are unable to reach or to afford safe drinking water by 2015'*.

Ensuring access to the basic level of service represents the primary objective of the Millennium Development Goal in relation to water, although the definition of the safety of water remains unclear. In 2000, this target was realised for the 82% of the global population who had a improved water source within one kilometre of their home or a household connection to a water supply. The remaining 18% (equivalent to about 1.1 billion people) are in the category of no access and are found largely in Asia and Africa and particularly in rural populations which are typically less well served than urban populations (WHO and UNICEF, 2000). This suggests a priority on ensuring at least access basic access in rural areas. It is important to note, however, that the rapid growth in urban populations suggests that figures for access in urban areas may reduce over time unless the pace of expansion of coverage is maintained (WHO and UNICEF, 2000).

Where at least basic access is already assured for all, a priority is to increase the numbers of households that reach the intermediate access level, where the evidence suggests further major improvements in health are achieved (Prüss *et al.*, 2002). Currently, only 47% of the global population has access to this level of service, a figure significantly lower than global access to improved sanitation of 60% (WHO and UNICEF, 2000).

Increasing numbers of households in this category will result in significant public health gains from likely better hygiene, maintenance of microbial quality of water and more time for child-care, productive activity and schooling. Such access is likely to also require that the supply is continuous, although there remains a dearth of direct evidence of the overall impact of intermittence on public health (Prüss *et al.*, 2002), although the risks in relation to contamination of supplies are well known (Regli *et al.*, 1993; Clark *et al.*, 1993). In many urban situations, it may be possible to move from no access to intermediate access without an intermediate phase of basic service level. Responding to local conditions and opportunities will be more effective than developing generic blue-prints for service level upgrading.

The achievement of an intermediate level of water supply service may create additional problems that will need to be addressed to maximise public health gains. Most notable are the disposal of sullage and improvements in drainage around individual dwellings and in communities. The presence of poorly drained water may lead to increased risks from insect vector-related diseases, may increase the risk of exposure to pathogens, particularly for small children who may play near or in water. It could potentially increase risks of schistosomiasis, which has been noted as an increasing problem in poorly drained urban areas (WHO, 1991).

Ensuring basic access to the currently unserved and increasing the numbers of people with intermediate access are complementary activities. There remains no doubt that ensuring at least a basic level of service remains a key international goal. At the same time, investment should not focus solely on this level of access, but should also be targeted on addressing moving increasing numbers of people to an intermediate level of access.

6.3 Global Assessment

In the Global Water Supply and Sanitation Assessment 2000 Report, improved sanitation types were all defined primarily at individual household levels, or at most shared by a few neighbouring households. By contrast, most definitions of improved water supply were defined as communal (basic access) levels of service.

If the definition of improved water supply were on-plot (intermediate access), which can be justified on the basis on health evidence, water supply access is actually lower than sanitation access. This has profound implications. Currently, there is rightly significant advocacy to reduce the sanitation access deficit. However, the evidence suggests that continued attention is required equally for improving services in both water supply and sanitation.

6.4 Emergencies and disasters

In emergency/disaster situations the provision of adequate safe water is of particular concern in order to control the spread of infectious disease and in particular to prevent large-scale outbreaks of disease. The provision of sufficient safe water for consumption and cooking is an absolute requirement and should never be compromised.

The reference volume of 7.5 litres for consumption must be available for use within the dwellings within an emergency context and the may the first goal in the first stages of an emergency response. Short term decreases in volumes available for hygiene purposes may have limited health implications provided effective use in hygiene, particularly handwashing, is promoted.

The emergency response should include design to provide water for hygiene and it would be rational to consider this in terms of service level in the same way as non-emergency situations. In terms of estimating source volume requirements, it can be assumed that provision of communal facilities will result in use of on average 20 litres per capita per day, if taps are provided to individual dwellings this will increase to 50 litres per capita per day and if multiple taps are provided this will increase further.

6.5 Quantity in health-based surveillance programmes

The role of the health sector in promoting better water supplies to maximise health gains should be to advocate for those interventions that will deliver greatest improvements in health. A key component of this role is the regular surveillance of water supplies in order to assess progress with meeting targets consistent with stated public health goals and to identify priority areas for intervention. WHO (1993) define surveillance as '*the continuous and vigilant oversight of drinking water supplies from a public health perspective*'.

Water quantity has traditionally be viewed as forming a key indicator for such surveillance programmes, alongside measures of quality, cost, continuity and coverage (Howard, 2002 ; Lloyd and Bartram, 1991; Lloyd and Helmer, 1991; WHO, 1997). Elsewhere it has been suggested that service level may be more appropriate (Bartram, 1999).

This review indicates that service level is more closely related to health than the quantity of water and also provides an indication of the likely volumes of water available and used by households. Quantity data is also difficult to collect and are often aggregated (for instance at community level) whereas water quantity or availability is experienced at the household level (Bartram 1999). There may be a value in assessing volumes used by households with higher service levels, in part to determine the influence their consumption has on users at basic level services. For such an approach to be useful, however, this must be matched against a set of surrogate variables – for instance distance, time, cost or reliability – in order for conclusions about a wider population to be drawn.

The literature suggests that some evaluation of the impact of cost and reliability of water supply on quantities of water used would have value within a surveillance programme, although this would not be expected to require frequent monitoring (Howard, 2002; Lloyd and Bartram 1991). There appears little justification for collection of such data in relation to distance, as the literature points to this only being significant between gross differences in service level and of limited value for assessing within-group variation at basic and intermediate level of service.

This indicates that estimates of access as described by service level and continuity in supply provide the most meaningful insights into the adequacy of water supply for health protection and can provide an indication of the quantities of water likely to be collected and used. This data is easily obtainable using inventories of water sources and connections, sanitary inspection of water supplies and water usage studies. There may be some value in collecting data on quantities of water collected in relation to cost, although the likelihood of relationship may depend on the availability of different types of water source. In situations where vendor usage is more common there would appear to be a justification of assessments of volumes of water collected.

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