FUTURE NEEDS AND PRIORITIES FOR DRINKING WATER AND HEALTH

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Summary

It is clear from recent literature reviews, from American Academy of Microbiology Reports and from WHO expert meetings, that we are a long way from guaranteeing safe drinking water even in the most developed nations. This chapter attempts to identify major knowledge gaps and summarize at least some of the needs and priorities for the future provision of safe drinking water. Obviously, the major benefits to human health are through basic hygiene and sanitation practices -- still much needed areas for public health intervention in many parts of the world. However, this chapter will emphasize more research-oriented needs and priorities. These include the need for a better understanding of biofilms and their control, improvements in risk assessment methodologies, the emergence of new disease, the balance between pathogens and disinfection-by-products, and the future promise of rapidly developing technologies.

1. Introduction

The concept of safe, cheap drinking water as an inalienable human right for everyone has emerged in the more developed nations in the latter part of the twentieth century. Although the quality of our source waters, and their protection, is recognized as the single most efficient factor in determining consistently high quality drinking water, the technology now exists to take wastewater and recycle it to potable water quality.

As cities have developed, both in the US and globally, both water distribution and waste collection systems have become more complex and far more difficult to maintain. Thirty percent leakage from water distribution systems appears to be a common estimate,
whether talking to utility personnel in Boston, USA, or Hyderabad, India. The fundamental difference between these two systems is pressure. According to the Hyderabad utility personnel, Hyderabad is able to provide a two-hour supply of water per day. The system therefore remains stagnant for twenty two hours per day and is highly susceptible to contamination through back-siphonage, cross connections, and biofilm regrowth. In contrast, Boston and other developed nation cities maintain pressure resulting in incredible wastage of treated, potable water, yet reduced risk to human health.

Now we have entered the twenty first century, what are the future options? While for many regions watershed protection is still problematic, filtration and disinfection technologies are constantly being improved. A typical multibarrier approach to provide safe drinking water is presented in Table 1.

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<td>1.</td>
<td>Watershed protection that minimizes anthropogenic and wildlife impacts on source water, including programs to reduce the impact of waterfowl, particularly near water intake sites.</td>
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| 2.    | A treatment system with sufficient capacity to maintain adequate pressure throughout the distribution system for 24 hours/day, and that minimizes opportunities for microbial colonization in the distribution system. This could include,  
- Coagulation-flocculation and sedimentation to remove colloids, associated microorganisms, debris and macroorganisms.  
- Preozonation to effectively kill microorganisms in source waters, reduce odor, taste and color, precursors for DBPs (Disinfection byproducts are formed by ozonation of source waters, including aldehydes and brominated byproducts (discussed in Boorman et al, 1999). UV disinfection, used extensively in wastewater treatment, is rapidly gaining acceptance as an alternative to ozonation.), and reduce the amount of chlorine/ chloramine necessary to maintain a system residual.  
- Filtration to further remove particulates and microorganisms, including granular or biological activated carbon to remove AOC.  
- Chloramination to provide residual disinfection, minimize biofilm formation and reduce DBPs, with intermittent chlorination and system flushing. |
| 3.    | A rigorous program to upgrade distribution system networks and prevent interconnections through leakage, backflushing, improper hydrant use, etc. |

Table 1. A multibarrier approach to maximize microbiological quality of water

A technology can always be developed to clean contaminated source waters, albeit at a high cost. It is harder, however, to find a technological solution to deteriorating
distribution systems. Replacing pipelines is an extremely slow and disruptive process, and lining existing pipes may only provide temporary solutions. Lining materials that are currently in use, e.g., cement and epoxy linings, may be susceptible to deterioration, particularly in microbiologically active environments.

There are many alternatives proposed for provision of safe drinking water, including separate potable and non-potable supplies, point-of-use treatment devices and bottled water. None of these alternatives are without risk to the consumer and are invariably many-fold more expensive than municipal supplies. Of course, there is a strong argument that centrally supplied drinking water is dramatically undervalued, and more appropriate costing of this invaluable resource would help to address some of the problems briefly listed above.

In the foreseeable future, drinking water is likely to continue to be supplied through distribution networks. What, therefore, do we see as future needs and priorities?

2. Risk assessment

To begin with, we are still unable to characterize and quantify health risks associated with drinking water meeting World Health Organization Standards. It is likely that those risks are minimal to individuals with no predisposing factors (e.g., compromised immunity). However, on a global scale it could be argued that the susceptible individuals are as common as the non-susceptible. In developed nations we think about the very young, the elderly, the pregnant and those with diseases that directly, or through treatment, compromise immunity. Even in developed nations, the burgeoning field of environmental health has shown us that exposure to pollutants in air, food and water can affect susceptibility to disease. Likewise malnutrition, stress and socioeconomic status (e.g., inner city communities) render individuals more susceptible. In developing nations, the burden of diseases may be vast and malnutrition levels high. Rapid industrialization also exposes populations to uncontrolled pollution, leaded petrol is still accepted as the norm, and smoking, drug, alcohol abuse and prostitution are rampant.

However, although exposures appear to be vast, diseases may not be apparent due to multiple prior exposures resulting in population immunity. This then is the paradox. By all the above criteria, these populations are highly susceptible, yet immunity results in lower than expected incidence of many waterborne diseases. This immunity must come at some cost to the individual - which provides some validation to the Disability Adjusted Life Years (DALY) approach to estimate burden of disease, which could take into account the reduced quality of life (and lifespan) from exposure to multiple infectious agents (and toxins).

A recent study by Arie Havelaar and colleagues in the Netherlands used the DALY approach to compare the risks of disinfection byproducts vs. infectious disease. They conducted a hypothetical case study involving a drinking water system typical of the Netherlands. Their goal was to compare the reduction in risk of infection with Cryptosporidium parvum from ozonation of the water source, with the potential risk of cancer from ingestion of bromate (formed by reaction of ozone and bromine compounds
in source water). Net health benefits (in DALYs) were calculated based on published clinical, epidemiologic, and toxicologic data on morbidity and mortality. Although bromate was produced in their model at concentrations exceeding US-EPA guidelines, they concluded that net benefits from ozonation outweighed risks by more than an order of magnitude, with a net benefit of approximately 1 DALY/million years. The DALY approach allowed the authors to consider life and health expectancy, including evaluation of the distribution of population susceptibilities. This approach provides a far more appropriate estimate of disease burden than can be obtained solely from annual mortality rates. Even so, considerable assumptions are made in 1) the exposure assessment; e.g., the median number of infectious *Cryptosporidium* oocysts, the median concentration of bromate, and the volume of water ingested; 2) in the hazard characterization; e.g., the shape of the dose response curves at low exposures, the applicability of rodent models to humans, and the distributions and models used to produce median parameter values and confidence intervals, 3) and in the risk characterization; e.g., assumptions made in calculating life years lost, years with disability and weightings for different population susceptibilities.

Paul Gale from the WRc-NSF Ltd., UK, has provided thoughtful analysis of the risk assessment process and has argued that distribution of pathogens, and in particular the protozoa, is extremely heterogeneous in drinking water. In other words, most consumers ingest zero *Cryptosporidium* oocysts and most water samples measure zero oocysts. However, a few individuals could consume a large number of oocysts. Gale argues that risk assessments based on median values obtained from spot sampling will underestimate risk as most samples are zero. Number of organisms present in a drinking water sample should be more accurately modeled as a distribution (in Gale’s example for *Cryptosporidium*, a Poisson-log-normal distribution is used). Daily risks of infection are then calculated for this distribution using Monte Carlo simulation. However, Gale also reports that risks predicted by simple use of the arithmetic mean are very similar to those using Monte Carlo simulation. The arithmetic mean of pathogen density may be a better predictor of risk than the median value, as it provides a weighting to any positive samples based on the actual number of oocysts.

Gale also argues that spot sampling is inappropriate, as even during outbreak conditions most spot samples are zero, and that continuous monitoring, as is currently recommended in the UK for *Cryptosporidium*, is necessary. Similar arguments could be applied to pathogenic viruses and, in fact, to any pathogens with low infective doses and/or a tendency to adsorb to particles/biofilms contributing to a heterogeneous distribution. Gale has constructed a large number of risk assessments based on the arithmetic mean, rather than the median, including risk assessments for *Cryptosporidium parvum*, *Escherichia coli* O157, rotavirus and Bovine Spongiform Encephalitis (BSE; see later discussion).

Assumptions are also clearly present in estimating consumption of drinking water and it is argued that these too should be modeled on a distribution. The dose response relationship between number of pathogens ingested and infection is highly variable based on individual susceptibility (including immunity from prior exposures). Infectious doses measured in healthy volunteers may bear little relationship to the range of infectious doses in an average population.
Where else does uncertainty arise? For any pathogen, its presence in drinking water may not be enough to characterize risk. Organisms may lose their infectivity/virulence in the drinking water distribution system or after exposure to disinfection; or conversely, they may increase or change in virulence and in their ability to resist antibiotics.

Our risk assessment approach examines individual organisms. We are in fact exposed to complex mixtures of both microbes and chemicals. Questions that arise from this are:

1) What are the synergistic effects (both in terms of infectious dose and disease outcome) of exposure to mixtures of pathogens, opportunistic pathogens and non-pathogenic microbes?
2) What are the synergistic effects of exposure to mixtures of microbes and chemicals? For example, could simultaneous exposure to high concentrations of a contaminant chemical and an infectious agent effect the pathogen’s infectious dose? Certainly, there is an argument that long-term exposure to chemical contaminants may increase susceptibility to infection.
3) How is a pathogen’s infectivity and exposure route altered by association with biofilms?
4) How is a pathogen’s infectivity and exposure route altered by intracellular survival within protozoa? (For example, it has been argued that the disease outcome from exposure to Legionella pneumophila could be related to mode of transmission; within biofilms, within protozoa or free-living).

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Biographical Sketch

Timothy Edgcumbe Ford has recently taken the position of department head of Microbiology at Montana State University (MSU), Bozeman, USA. He also retains an adjunct appointment at the Harvard School of Public Health, Boston, Massachusetts, USA where he was an Associate Professor of Environmental Microbiology and Director of the Program in Water and Health. He was a Faculty member in the Department of Environmental Health at the Harvard School of Public Health from 1992 until 2002. Prior to 1992, he was a Research Fellow and Lecturer in the Division of Applied Sciences at Harvard University.

His research interests (resulting in over 115 publications, to date) have included source and drinking water microbiology, microbial cycling and transformation of pollutants, surface microbiology (biofilms), microbiologically influenced deterioration of materials, and microbial populations as biomarkers of environmental stress. He has both directed and participated in water quality related projects in the US, Canada, the UK, Honduras, Mexico, India and Russia. Current research projects focus on the fate of opportunistic pathogens in drinking water biofilms, epidemiological studies on water and international health, and microbial interactions with pollutants.

Relevant activities have included:

Chair, Congressional briefing on "Increased Flooding Events and Risks to Human Health" Washington, DC (1998).

Chair, Congressional briefing on "Water, Population and Human Health" Washington, DC. (1999).

Chair, Congressional briefing on "Genetically Modified Crops" with Sea Change, Washington, DC.


Steering Committee member: American Academy of Microbiology Scientific Colloquium on “Infections through the Gastrointestinal Tract,” Galway, Ireland, 2002


Waksman Foundation for Microbiology Speaker, 2003/2004

Chair, International Colloquium on Protecting Public Health in Small Water Systems, Bozeman, Montana, 2004

Member, editorial board of the Journal of Industrial Microbiology and Biotechnology

Member, editorial board of the Journal of Environmental Science and Health

Member, editorial board of Environmental Engineering Science