# HUMAN HEALTH RISKS ASSOCIATED WITH WATER REUSE

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## Contents

## Summary

The human health risks associated with water reuse are not only related to the various treatment barriers used, but also the nature of the society that produces and reuses the effluents. At the one extreme, direct potable reuse (i.e. introducing reclaimed water directly into a water distribution system) cannot be considered a safe practice until we understand more about the possible risks posed by trace levels of organics and the reliability of barriers to pathogens. The apparent lack of adverse health outcomes in Namibia and various demonstration sites may well reflect more on the lack of sensitivity of such studies rather than negligible actual effects.

At the other extreme, indirect reuse and non-potable reuse/recycle are already viable options for many parts of the world. As progress with risk assessment and epidemiology is made, further refinements will also be made in what contributes to risks and therefore how they may be avoided/controlled. Particular areas needing extensive study are the impacts of pharmaceuticals, endocrine disrupters, and the role of biofilms, where pathogens may accumulate after treatment.

Monitoring recycled or reclaimed water systems has not been directly discussed in this chapter. Nonetheless, while it is not cost-effective to have ongoing extensive chemical

and microbiology monitoring systems, it is critical to the long-term security of the industry that treatment performance indicators are developed and where possible, brought on-line for control purposes.

## 1. Introduction

Solutions to human health-related water problems have historically focused on breaking the chain in the return of disease-causing organisms (pathogens) or toxic chemicals to humans. Important waterborne agents are generally regarded to be viral, bacterial and parasitic protozoan microorganisms or helminths (worms), along with various inorganic compounds (heavy metals, fluoride, nitrate etc.) and organic chemicals (pesticides, hormone disrupters etc.). This article summarizes the issues associated with the various hazard groups likely to be present in reclaimed or recycled waters.

When considering water-related risks, it is important to note that human health cannot be viewed independently from the environment. Whilst sanitation concepts developed in the late nineteenth century have supported exponential growth throughout the twentieth century, it is clear we are running out of fresh water to continue this trend through the twenty-first century. The majority of the world, for example, will be urbanized by the middle of the twenty-first century, with most people living within 50 km of a coastline. Even today, sanitation solutions contribute either directly or indirectly to many of the problems faced by society, including water pollution, scarcity of fresh water, food insecurity, destruction and loss of soil fertility, global warming, and poor human health as well as loss of life.

In our endeavor to provide conventional and reclaimed sanitation systems, we have used and contaminated large quantities of fresh water, and destroyed land and marine ecosystems. Various fecal indicators are still found and waterborne outbreaks still occur. It is therefore fair to conclude that our best efforts to treat or shunt excrement have failed to protect the environment as well as human health. The emerging discipline of sustainable or eco-engineering is a clear indication that current methods of waste disposal are insufficient to ensure public health safety in the long-term.

The purpose of this review is to not only to present an appreciation of the pathogens and chemicals which are of concern in reclaimed or recycled waters, but to also highlight the interaction with related concerns, such as disinfection by-products, pharmaceuticals and nutrients. An emerging tool used to balance these often-competing concerns is risk assessment. The risk assessment paradigm is therefore introduced first, so that one may develop an understanding of how to both quantify and prioritize risks as essential attributes required in the future for better decision-making with reclaimed systems.

## 2. Risk Assessment Paradigm

Traditionally, studies of illness within communities (epidemiology) have been used to assess the impacts of chemical and microbial hazards. The lack of documented incidences of outbreaks traceable to the reuse of wastewater however, has lead many to conclude that stringent quality standards do not appear to be economically justifiable. On the other hand, it is important to identify the generally poor sensitivity offered by traditional epidemiological studies. Furthermore, background illness within a community (endemic) may differ markedly between communities, further masking the likely detection of outbreaks (epidemics) (see Figure 1).

The apparent absence of reclaimed wastewater-associated illness can therefore be seen more as a reflection of the lack of sensitivity to detecting it rather than reality. Back in 1983, the National Research Council published recommended principles and methods covering cancer and non-cancer risk analysis. The NRC risk assessment paradigm for human health effects consists of fours steps (Table 1), and has not changed significantly in recent years. A decade after the NRC chemical risk assessment proposal, Haas (1999) demonstrated the usefulness of the exponential and beta-Poisson pathogen dose-response models (absence of threshold, Equations (1, 2)), which opened the way for quantitative microbial risk assessment (MRA) of human pathogens.

| **Step** | **Aim** |
|---|---|
| 1. Problem Formalization and Hazard Identification | To describe acute and chronic human health effects associated with any particular hazard, including toxicity, carcinogenicity, mutagenicity, developmental toxicity, reproductive toxicity, and neurotoxicity. |
| 2. Exposure Assessment | To determine the size and nature of the population exposed and the route, amount, and duration of the exposure. |
| 3. Dose-response Assessment | To characterize the relationship between various doses administered and the incidence of the health effect. |
| 4. Risk Characterization | To integrate the information from exposure, dose-response, and health steps in order to estimate the magnitude of the public health problem and to evaluate variability and uncertainty. |

Table 1. Risk assessment paradigm for human health effects (adapted from Haas, et al., 1999)

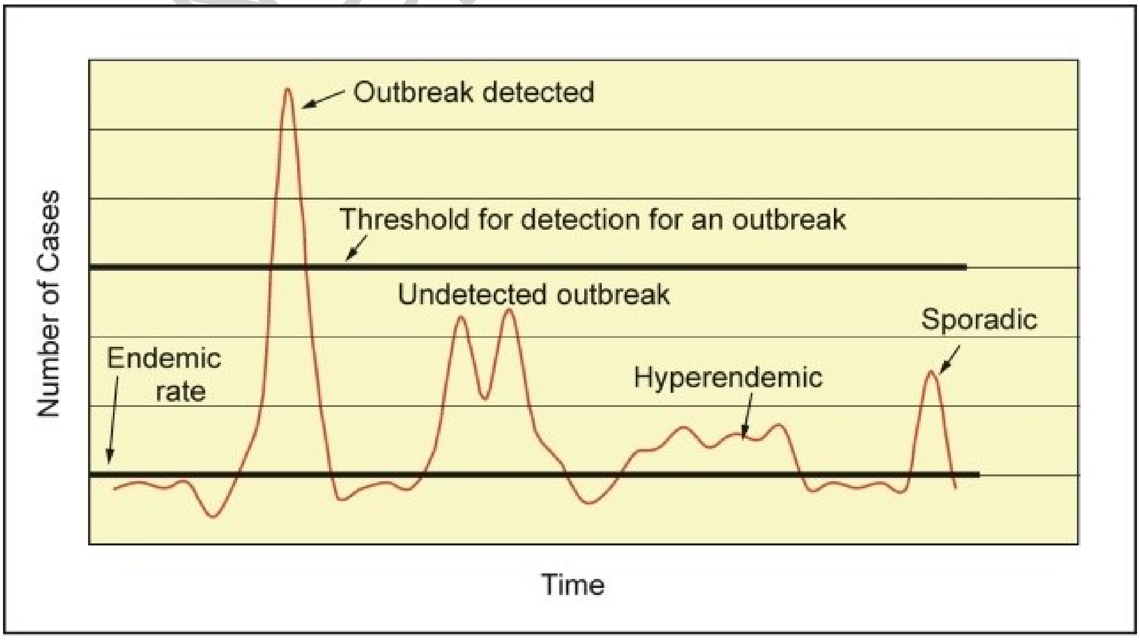

Figure 1. Epidemic to endemic illnesses as detected by epidemiologic studies (modified from Frost *et al.*, 1996).

Looking at the dose–response curves in more detail, the single hit models (e.g. only one pathogen particle needed) were first used in the fifties to describe processes associated with radioactivity. In the sixties, two virologists developed what is currently termed the “beta-Poisson” model to describe plant leaves infected with tobacco mosaic virus (Equation (1)). During the 1990’s, MRA has been applied to the development of drinking water quality guidelines.

Exponentia 1 model : $\text{Probability}_{\text{infection}} = 1 \exp(-rD)$ (1)

where
D= pathogen dose;
r = fraction of pathogens that survives to produce an infection.

Beta –Poisson model : $\text{Probability}_{\text{infection} = 1\ (1\ +} (D / \beta)^{-\alpha}$ (2)

where
D= pathogen dose; $\alpha$ and $\beta$ are parameters to fit the dose-response curve.

Whilst the conceptual framework for both chemical and microbial risk assessments is the same (Figure 2), pathogens however, differ from toxic chemicals in several key ways:

(i) The variability of different strains of the one pathogen to cause disease (differing virulence).
(ii) This virulence can evolve as the pathogen passes through various infected individuals.
(iii) Pathogens can be passed from one person to many (secondary spread), from either healthy but infected (asymptomatic) or ill (symptomatic) hosts (e.g. ratio of secondary to primary cases of 0.33 for *Cryptosporidium parvum* to over 1.0 for *Giardia lamblia* and Norwalk virus.
(iv) Whether a person becomes infected or ill depends not only on the health of the person, but also on their pre-existing immunity and pathogen dose.

Risk assessment commences with a formalized procedure known as problem formulation to identify all possible risks and their pathways from source(s) to recipient(s). To reduce the costs associated with quantifying all of these hazards in detail, a screening-level risk assessment is used to identify chemicals or pathogens of potential concern, using most conservative data and assumptions. Next, a more detailed assessment is only made for hazards identified of potential concern. The environmental concentrations and dose-responses of these selected hazards are then combined to characterize the risks, typically on an annual basis. Iterative cycles of the process draw out more detail and become more quantitative. With the use of additional information (political, economic, etc.), risks estimates are used by risk managers to formulate decisions (Figure 2).

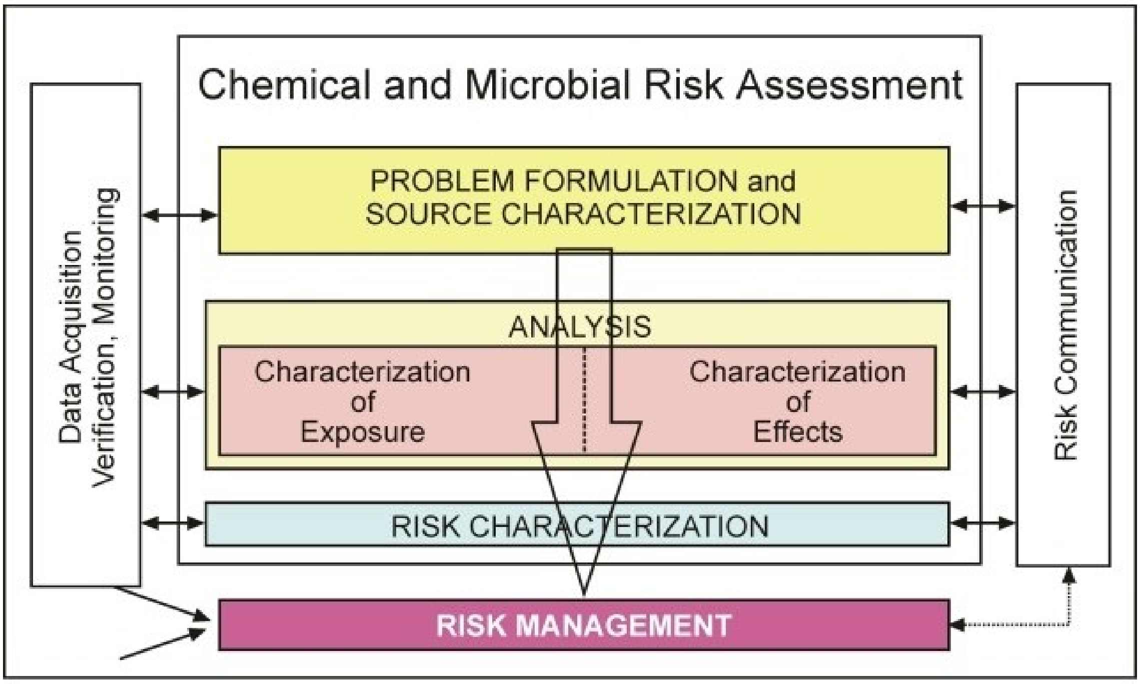

Figure 2. Generic approach to undertaking chemical or microbial risk assessment.

Refinements of the risk assessment approach include stochastic estimation of hazard exposures and dose-responses, as well as cost–benefit analyses. In this way, risk assessment is a structured, formalized approach for which all assumptions should be transparent for critical review. Compared to epidemiologic studies, risk assessment may be 3 to 5 orders of magnitude more sensitive. Risk assessment, however, should be used in concert with epidemiology to assist in setting rational guidelines for hazards associated with waters, rather than relying on unsubstantiated indicators such as coliforms (discussed in Section 3).

An interesting development in risk assessment is its application to the whole system approach, as used in the food industry. This approach is called hazard analysis critical control point (HACCP), and identifies criteria (critical limits) to ensure that the activities at a specified critical control point (CCP) are under control. It therefore follows that the whole system is analyzed to identify the CCP’s, monitoring systems and corrective action. Havelaar (1994) has applied HACCP to water supply, and the approach could be readily applied to reclaimed water systems. HACCP would imply a complete description of activities at each CCP, taking into account parameters such as pathogen distributions in source waters, particle removal in filtration, measurement of disinfectant concentration and control of pipe biofilm growth in distribution systems.

The following sections identify key hazards in reclaimed water systems, which are then applied with some examples within the risk assessment approach. Before proceeding however, an important community risk-based question is: who is at risk? Haas, et al. (1996) have suggested that up to 20% of the US community may be considered immuno-compromised. This susceptible sub-population includes the very young, the elderly, pregnant women, and the immuno-compromised. Thus a secondary question is for whose safety do we design a water reuse system, given that people may have a choice in their sources of waters?

To aid in answering these questions, it is worth considering that more than half of the documented deaths from gastroenteritis and hepatitis A illnesses occur in the elderly in developed countries. Furthermore, the overall ratio of illness to death (case fatality ratio) for food-borne bacterial gastroenteritis outbreaks in nursing homes is 10 times greater than for the general population. Pregnant mothers suffer from a case fatality ratio from hepatitis E infections ten times greater than that for the general population during waterborne disease outbreaks. In addition, cancer patients undergoing chemotherapy, and transplant recipients, are at significantly greater risk of dying from enteric viral infections than the general population. Hence, enteric diseases are most common and devastating among the immuno-compromised.

A good example of our evolving appreciation of waterborne risk pathogens is seen with *Cryptosporidium*, until recently a dominant cause of deaths amongst immuno-compromised people. Recent drug therapies and education however, appears to be decreasing its prevalence amongst the immuno-compromised. During two recent North American waterborne outbreaks of cryptosporidiosis (Milwaukee and Las Vegas), indicated mortality rates in the immuno-compromised ranged from 52% to 68%. Alternatively, based on those predominantly infected by *Cryptosporidium* via water, it appears from an estimate for New York, that more than 6000 infections would be expected to be waterborne, with 99% occurring in the non-AIDS categories. Perz, et al (1998). however, went on to estimate that three reported illnesses would occur out of every 10,000 infections in non-AIDS adults, with a 10-fold higher probability in the non-AIDS pediatric subgroup. In contrast, the majority of infections occurring in the AIDS subgroup were predicted to result in reported cases. Hence, when their model was applied to the New York City population, the calculated number of tap-water-related cases per year in the non-AIDS subgroups was six (95% CI 1-29) versus 34 (95% CI 6-240) in the AIDS subgroups.

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## Biographical Sketch

**N. J. Ashbolt** has been an Associate Professor in the School of Civil and Environmental Engineering, the University of New South Wales, Sydney, Australia since 1994. Prior to that time he was the principal microbiologist, Sydney Water Corp. His Ph.D. was undertaken on the microbial ecology of composting waste eucalyptus bark with biosolids and fish wastes (1984). Since then he as worked in industry and government research organizations, covering microbial issues associated with sugarcane mill wastewaters, mineral leaching of sulphidic ores, hypersaline Antarctic lakes ecology and wastewater reclamation microbial risks. Current research direction is focused on molecular and conventional identification of environmental pathogens in waters, effluents, sediments and biofilms, and the interpretation of this data with state-of-the-art quantitative microbial risk assessment methods. Dr. Ashbolt has active research collaborations with the Swedish Institute for Infectious Disease Control (Stockholm) and the Institute for Medical Research (Kuala Lumpur) and is a member of the WHO microbial guidelines working group. He has published over 65 journal articles, 10 book chapters and holds two joint patents.