Workshop summary: estimating waterborne disease risks in the United States

Gunther F. Craun and Rebecca L. Calderon

ABSTRACT

A workshop was held in Atlanta on July 7–8, 2005, to evaluate the epidemiologic and other information available for estimating endemic waterborne illness risks in the United States. Each paper written for this special issue was discussed and fourteen recommendations were made based on the discussion. In addition, seven major data gaps were identified as being key to reducing the uncertainty associated with a calculation of a national estimate. This summary is provided to help regulatory officials, public health professionals, and others better understand the health measures being estimated and adequacy of the current risk information. The summary also provides a blueprint for researchers interested in studying the endemic and epidemic risks of microbes in drinking water.

Key words | endemic disease, epidemic disease, gastroenteritis, gastrointestinal illness, waterborne disease, waterborne outbreaks

Gunther F. Craun (corresponding author)
Gunther F. Craun & Associates,
101 West Frederick Street, Suite 207,
Staunton, VA 24401,
USA

Rebecca L. Calderon
National Health & Environmental Effects Research Laboratory,
Office of Research & Development,
US Environmental Protection Agency,
Research Triangle Park NC 27711,
USA

INTRODUCTION

Section 1458 (d) (1) of the 1996 amendments to the Safe Drinking Water Act (SDWA) requires the Administrator of the US Environmental Protection Agency (EPA) and the Director of the Centers for Disease Control and Prevention (CDC) to jointly conduct pilot waterborne disease occurrence studies for at least five major communities or public water systems, prepare a report on the findings, and develop a national estimate of waterborne disease occurrence. At three previous workshops, participants recommended a research agenda to fulfill these requirements. The primary goal of the research is to provide quantitative information about the endemic waterborne attributable risk associated with public water systems in the United States. During the workshops, participants agreed that (1) microorganisms were the drinking water contaminants of greatest concern and (2) gastrointestinal illnesses should be studied, at least initially.

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Several of the studies recommended by the workshop participants have now been completed. These include household and community interventions and research on water consumption patterns and usage behavior. Observational epidemiologic studies of waterborne illness risks have also been published in the scientific and medical literature (Craun & Calderon 2006), and acute gastrointestinal illness (AGI) risks were estimated for the US population (Roy *et al.* 2006). Authors of the preceding papers in this special issue of the *Journal of Water and Health* and selected reviewers participated in a workshop during July 7–8, 2005 to review these studies and evaluate the adequacy of information to estimate waterborne risks, identify data gaps, and recommend additional research needs.

A NATIONAL ESTIMATE

During the workshop, several approaches for estimating waterborne risks were illustrated using the available information from epidemiologic studies conducted in the United States and other developed countries. These

approaches and estimates are presented in this issue (Colford *et al.* 2006; Messner *et al.* 2006). Although some information is available about risks for persons that may be more susceptible to illness (e.g. children, elderly, immunocompromised), the estimates do not specifically consider special population risks. The estimates also do not consider risks associated with non-public drinking water systems, bottled water, or recreational waters. Since only gastrointestinal symptoms are considered, the estimates do not reflect all waterborne illness risks. In addition, gastrointestinal illnesses may be linked to chemical contaminants in drinking water, and these illnesses are not included in the risk estimates. Similar transmission dynamics apply for waterborne outbreak and endemic illnesses, and outbreak statistics can help inform the endemic risks (Craun *et al.* 2006*b*).

Definition of illness

Case symptoms vary according to the needs of each study. AGI symptoms generally include diarrhea and/or vomiting, with vomiting being the more objective symptom. Usually, persons remember a recent vomiting event and recognize the outcome without further explanation of specific symptoms. Diarrhea, however, should be explicitly defined for study participants. The usual definition is three or more loose or non-formed stools in a 24-hour period. Unless adequately defined, a loose stool can be subject to individual interpretation, and three loose stools per day may be normal for some persons. Other signs and symptoms that have been considered include bloody or mucoid diarrhea, tenemus, fever, nausea, cramping, acute anorexia, and malaise. Cramps and nausea together with missing time from work or school have also been used. Some of these symptoms may be used to help in diagnosing a specific etiology or in making decisions to collect and analyze clinical specimens. Unless cases are laboratory-confirmed, AGI is of undetermined etiology. Viruses, bacteria, or protozoa may be the cause, but AGI symptoms do not necessarily indicate a microbial etiology. Household- and community-intervention studies have considered waterborne AGI risks. Case-control studies have considered laboratory-confirmed, symptomatic cases of a specified etiology (e.g. cryptosporidiosis, giardiasis), and cohort studies have considered AGI and specific diseases.

Cases may be either primary and secondary, but, unless identified, they cannot be distinguished in the results. Persons who have become ill after they ingest contaminated drinking water are primary cases. Secondary cases are infected by a primary case, usually by person-to-person transmission. If secondary cases are identified in the studies, only primary cases are considered in the estimates.

Most epidemiologic studies considered symptomatic cases. However, persons may become infected without exhibiting symptoms. Information about asymptomatic cases is important because infected persons, whether symptomatic and asymptomatic, may contribute to secondary transmission increasing the endemic risk (Craun *et al.* 2006a). Some waterborne pathogens, such as *Cryptosporidium*, may confer protective immunity, and it is important to assess the prevalence of infection for this protozoan in order to provide information about the community's susceptibility to symptomatic illness (Casemore 2006).

Recommendations

Investigators should clearly describe the signs and symptoms being studied and the method used to identify cases in their studies (e.g. self-reported by diary entries, physician surveys, telephone surveys, emergency-room records). A standard definition of AGI should be used in future studies, especially those conducted or funded by EPA and CDC. This will ensure comparable results for revising the current risk estimates. In developing a standard definition, investigators should consider whether a different definition of diarrhea (i.e. any bowel movement that is different than normal) is more useful. Investigators are encouraged to more completely identify cases in their studies as primary or secondary and specify whether laboratory-confirmed infections include asymptomatic cases.

Measures of risk

Measures of endemic waterborne risks include relative risk, odds ratio, attributable incidence, attributable risk (AR), population attributable risk (PAR), attributable fraction, and etiologic fraction. Craun *et al.* (2006*a*) define and

discuss these measures in this issue. When an investigator reports a waterborne risk measure as "attributable", it is presumed that exposure to microbes in drinking water is the cause of the excess risk. The implication is that removal of the exposure through an improvement in the microbial quality of drinking water, water treatment, or system operation can prevent or reduce this number or fraction of cases. However, some attributable risk measures refer to the removal of the exposure among only the exposed members of the population; others refer to the removal of the exposure among the general population of both exposed and unexposed persons (Craun *et al.* 2006*a*). It is important to understand to which of these populations the risk refers. Attributable benefit refers to a decrease in illness risk that may be associated with improved water treatment. Attributable risk measures may also be used to describe the excess risk associated with a previous water treatment (e.g. no filtration of surface water).

A related issue is how to interpret "null" risks or results of studies in which no statistical differences in risk are found between exposed and unexposed persons. "Null" findings can be better understood when investigators provide the statistical power of the study to detect a specified risk and when confidence intervals are provided for the risk estimate.

Recommendations

Investigators are encouraged to report the statistical power of the study to detect a defined risk. Because of confusing terminology, investigators should show computations of attributable risks and clearly define the population or exposure to which the risk refers.

Illness burden

Although many cases are relatively mild, AGI may result in hospitalizations, emergency-room or physician visits, or death. A number of ways in which AGI severity can be measured include: the number of physician visits or hospital admissions, duration of illness, time missed from school or work, change in normal daily activities, and medication requirements. Also informative are monetary (e.g. cost of illness, willingness to pay) and population health (e.g. disability adjusted life year or DALY, quality adjusted life year or QALY) measures (Rice *et al.* 2006). Severity measures do not necessarily include chronic sequelae that may be associated with some waterborne illnesses. Limited information is available about the incidence of chronic sequelae associated with many waterborne pathogens.

Recommendations

Future estimates of waterborne risks should include one or more measures of illness severity. Research should be conducted to better understand the long-term effects that may be associated with waterborne diseases.

Waterborne disease outbreaks

Analyses of reported outbreaks can provide information about important water system deficiencies and etiologic agents, and this information can be used to help inform endemic risk estimates. Workshop participants agreed that the number of illnesses associated with waterborne outbreaks reported in the United States is likely to be relatively small compared with endemic illnesses (Craun *et al.* 2006*a*). However, not all waterborne disease outbreaks are recognized, investigated, or reported. The true incidence of waterborne outbreaks and associated illness is greater than is reflected in the reported statistics. Improved surveillance activities can help detect currently unrecognized outbreaks. For example, active surveillance conducted during 1980–83 by the Colorado Department of Health for waterborne diseases resulted in the investigation of 18 waterborne outbreaks (Hopkins *et al.* 1985). During the previous three years when surveillance was passive, six waterborne outbreaks were reported, and some 20 additional clusters of gastrointestinal illness suspected to be waterborne were not investigated. Anecdotal evidence suggests that the states that have reported the most waterborne outbreaks are those in which surveillance activities were improved. For example, Florida reported most of the waterborne outbreaks during 2000–2001; almost all were reported by a single health district with enhanced surveillance (Blackburn *et al.* 2004). These examples emphasize the extent to which improved surveillance may affect the reporting of outbreaks.

Recommendations

Future estimates of endemic waterborne risks should include the outbreak statistics with appropriate cautions about the limitations of the waterborne outbreak surveillance system. Studies should be conducted to assess the extent to which outbreaks may be under-reported. States and localities should be encouraged to improve surveillance activities to better detect outbreaks, increase laboratory support for water and clinical analyses during outbreak investigations, and include engineers and environmental specialists in investigations.

EPIDEMIOLOGIC AND SEROPREVALENCE STUDIES

Workshop participants discussed the results of epidemiologic studies of endemic waterborne risks (Tables 1–4). A more detailed description of these studies is provided elsewhere in this special issue (Calderon & Craun 2006; Casemore 2006; Colford *et al.* 2006; Craun & Calderon 2006).

Household-intervention studies

Household-intervention trials assessed AGI risks for persons who consumed tap water with and without additional treatment provided at the tap. An increased risk of AGI was associated with tap water in Canada (Payment *et al.* 1991, 1997), but studies in the United States and Australia did not find an increased risk among tap water users (Table 1). When interpreting study results, differences in source water quality, treatment efficacy and operation, and distribution system integrity are important to consider.

Methodological limitations may also be a source of the differences observed in risk. A key difference is the blinding of study participants in terms of exposure. In the US and Australian studies, participants assigned to the exposed group received a "sham" treatment device for their tap water and, thus, were blinded as to their exposure status. In the Canadian studies, participants received either a tap water treatment device or no device. Since illness is self-reported, not blinding the participants may result in reporting bias.

Recommendations

The next generation of household-intervention studies in the United States should consider a site where the water treatment is highly challenged in terms of both source water quality and treatment effectiveness. The distribution system of the selected site should also be described in detail, and particularly vulnerable portions of the distribution system should be identified for separate analyses of potential risks. Results from such a study should provide an upper bound risk estimate that is appropriate for vulnerable US water systems. Future studies should include blinding of both participants and investigators who collect information from participants.

Opportunistic natural experiments: community-intervention studies

Community-intervention studies in Massachusetts (Table 1) and Northwest England (Table 2) found a decreased risk of illness after the installation of granular or membrane filtration, respectively (Calderon & Craun 2006). Preliminary analyses suggest that a decreased AGI risk was associated with the installation of membrane filtration for a contaminated groundwater system in Texas, but in Washington State, decreased AGI risks were not observed after the granular filtration and improved disinfection of a high quality surface water source. In both Texas and Washington, the drinking water quality was improved. Two studies in Australia evaluated surface water systems that upgraded their treatment to either disinfection or disinfection and filtration, but no measurable changes in risk were observed. Workshop participants agreed that the results of these studies can help inform the national estimate, but the current information is sparse and limited to select water sources and treatment. The discrepancy in risks may be due to differences in source water quality, low statistical power, or other study limitations.

Selection of future study sites depends on scheduled changes in water treatment processes. Disinfection changes or filtration may be considered by many small systems that use vulnerable groundwater sources. Filtration may be considered by additional surface water systems that have

Table 1 | Endemic waterborne gastroenteritis risks in community water systems

Location	Type of study (residents all ages unless noted)	Relative risk (95% CI) & AR% if available	Water exposure
France	Cohort[1]	RR = 1.14 (0.67–1.92)	Untreated GW; + fecal coliform
France	Cohort	RR = 1.19 (0.96–1.48) RR = 1.24 (1.06–1.45)	10–20 *Giardia* cysts/100L >20 *Giardia* cysts/100L
Norway	Cohort[2]	RR = 0.4 (0.2–0.9)	Chlorinated water
Australia	Community intervention[3]	OR = 1.07 (0.72–1.21)	Unfiltered and undisinfected SW
Massachusetts, USA	Community intervention	AR% = 34%	Unfiltered SW
Melbourne Australia	Household intervention[4]	IRR = 0.99 (0.85–1.15)	Unfiltered SW
		AR% = 4%	
Texas, USA	Community intervention[5]	NA (increased risk preliminary results)	Unfiltered GW under influence of SW
Washington State, USA	Community intervention	NA (no increased risk preliminary results)	Unfiltered SW
Australia	Community intervention	NA (no increased risk)	Unfiltered SW
Montreal area, Canada	Household intervention	Tap water:AR% = 34%	Filtered SW
Montreal area, Canada	Household intervention	Tap water AR% = 12–17%	Filtered SW
		TP water AR% = 3%	
California, USA	Household intervention[4]	IRR = 1.32 (0.75–2.33)	Filtered SW
		AR% = 24%	
Davenport, Iowa, USA	Household intervention[4]	IRR = 0.98 (CI 0.87–1.10)	Filtered SW
		AR% = < − 0.08%	

[1]Towns >400 population;
[2]Age <15 yrs.;
[3]Admissions for gastroenteritis at childrens' hospital;
[4]Immunocompromised excluded;
[5]36 + yrs.;
NA = Not available; SW = surface water source; GW = groundwater source; TP water = treated water before distribution to the system.

identified sources of contamination. The likelihood is small that the two largest unfiltered, surface water systems in the United States will be adding filtration in the near future, but these large unfiltered systems may change disinfection processes and optimize operation.

Recommendations

The next generation of community-intervention studies should include drinking water systems that are considering changes in either treatment optimization or disinfection (e.g. UV). Studies of the benefits that may be associated

Table 2 | Endemic waterborne cryptosporidiosis risks in community water systems

Location	Type of study (residents all ages)	Relative risk (95% CI)	Water exposure
Melbourne, Australia	Case-control	OR = 1.3 (0.9–2.1)	Unfiltered SW
Adelaide, Australia	Case-control	OR = 1.0 (0.7–1.6)	Filtered SW
Northwest England	Community intervention	IRR = 0.21 (0.1–0.4)	Filtered SW
San Francisco Area, USA	Case-control[1]	OR = 6.76 (1.37–33.5)[3]	Tap water
	Case-control[2]	OR = 0.92 (0.16–5.30)	Tap water
Northwest England	Case-control	OR = 1.40 (1.14–1.71) [3]	Tap water[4]; per pint daily
NW England & Wales	Case-control	OR = 1.135 (1.010–1.265) [3]	Tap water[4]; per glass daily
FoodNet states, USA	Case-control	OR = 0.7 (0.4–1.1)	Tap water

[1]AIDS patients;
[2]Immunocompetent population;
[3]Multivariate; all others univariate;
[4]98% of study population used community water system (at least 65% of which used unfiltered SW, 35% used either filtered or unfiltered SW);
SW = surface water.

with changes in treatment should be conducted in a large surface water system or several smaller systems that are adding filtration to a groundwater under the direct influence of surface water. The studies should be conducted in areas that can provide risk information applicable to a large percentage of the US population and be of sufficient statistical power.

Combined household and community-intervention studies

An important strength of the household-intervention study is that study participants are randomized to receive exposure to either tap water or additionally treated tap water. However, a limitation of this study type is that the water quality is changed only at the home tap. Study

Table 3 | Endemic waterborne giardiasis risks in community water systems

Location	Type of study (residents all ages unless noted)	Relative risk (95% CI) [90% CI]	Water exposure
Vermont USA	Cohort	RR = 1.9 (1.1, 3.3)	Unfiltered SW
Dunedin, NZ	Cohort	RR = 3.32 [1.1, 10.1]	Unfiltered SW
Dunedin, NZ	Case-control	OR = 1.8; [0.5–6.5]	Unfiltered SW
Auckland, Australia	Case-control[1]	OR = 8.6 (3.5–21.2)	CWS other than Auckland
Southwest England	Case-control	OR = 1.3 (1.1–1.5)[2]	Tap water; each additional glass daily

[1] < 5 yrs.;
[2]Multivariate; all others univariate;
SW = surface water; CWS = community water system.

Table 4 | Endemic waterborne campylobacteriosis risks in community water systems

Location	Type of study (residents all ages)	Relative risk (95% CI)	Water exposure
Quebec, Canada	Case-control	OR = 1.9, – = 0.03	Tap water
Denmark	Case-control	OR = 4.23 (1.18–15.04)	Tap water with bad taste or smell
Finland	Case-control	OR = 0.52 (0.26–1.02)	Large CWS
		OR = 0.80 (0.37–1.72)	Small CWS
Christchurch, NZ	Case-control	OR = 0.6 (0.1–1.9)	CWS other than Christchurch
Cardiff, Wales	Case-control	OR = 1.51 (1.06–2.18)	Tap water

CWS = community water system.

participants may also consume water at other locations (Davis *et al.* 1998). In a community-intervention study, the water treatment change affects taps at all locations, and treatment randomization is not possible.

Recommendation

Workshop participants suggested that, among the next generation of studies in the United States, investigators should consider the feasibility of a household-intervention study nested within a community-intervention study.

Cohort studies

The information from cohort studies is also sparse. Several cohort studies found increased risks of giardiasis among persons using unfiltered surface water (Table 3). In Norway, consumption of chlorinated tap water was protective for AGI in children under 15 years of age whereas increased risks were associated with use of individual water systems (Table 1). Results of studies in France found differing AGI risks depending on the water quality (Craun & Calderon 2006).

Recommendation

Since a cohort study is very expensive to conduct and offers little advantages over the other study designs, no additional studies are recommended in the United States. However, if cohort studies are planned to study other exposures, investigators are encouraged to consider possible differences in water quality exposures among their cohorts.

Case-control studies

Case-control studies evaluated waterborne risks for cryptosporidiosis, giardiasis, and campylobacteriosis (Tables 2–4). No case-control studies of waterborne AGI were found in the published literature. Since these studies are less expensive to conduct than an experimental or cohort study, workshop participants discussed the possibility of such a study for AGI. These studies would require a systematic way of identifying AGI cases in the study population, since the vast majority of AGI cases in the United States are not reported. Case-control studies are usually conducted where there is ongoing surveillance for the illness.

Recommendations

Case-control studies can provide information about the relative risks of waterborne versus other modes of transmission for AGI or specific diseases and, thus, should continue to be conducted. A case-control study of waterborne AGI would not likely be feasible unless it is conducted in conjunction with ongoing disease surveillance that includes AGI cases. A study of waterborne AGI might be possible if it could be nested within the FoodNet surveillance system, which is described by Roy *et al.* (2006). The feasibility of such a study should be evaluated. The feasibility of studying

other waterborne diseases such as giardiasis, shigellosis, or toxigenic *E. coli* gastroenteritis should also be evaluated. Although the FoodNet study population is not representative of the US population, it does represent a large population with potentially various types of water systems and exposures.

Seroprevalence studies

The most extensive information about seroprevalence is available for *Cryptosporidium*, a waterborne pathogen of significance because of its resistance to chorine disinfection (Table 5). A serological response based on current antibody tests indicates that a person has been infected but does not imply that the person has suffered symptomatic illness (Casemore 2006). However, disease rates may be lower than expected and this may be due to protective immunity of the resident population. Not all *Cryptosporidium* strains will necessarily be pathogenic or virulent in humans but may be capable of conferring or boosting immunity. Although periodic exposures may offer some protective immunity for illness, the role of drinking water as a source of periodic, low-level *Cryptosporidium* exposure is not clear. Information from current prevalence studies cannot be used to estimate the proportion of the population that may show a higher response due to drinking water exposures.

Recommendations

Studies should be designed and conducted to better estimate the prevalence of waterborne *Cryptosporidium* infection Research is also needed to assess the possible benefits (e.g. protective immunity) that may be associated with *Cryptosporidium* exposures. Epidemiologically based microbial risk assessment modeling may help provide insight into these seroprevalence studies (Soller 2006).

Additional *Cryptosporidium* antigens and cross-reacting antigens should be further investigated, and the relative sensitivity and specificity should be determined for currently developed antigen tests for antibodies in persons who have been infected with species other than *C. parvum*. Because the study of serological markers of infection and possible protective immunity of waterborne pathogens is an evolving research area, a repository should be established for the storage of sera samples. This repository would allow for additional analyses of the sera should current analytical methods be improved for *Cryptosporidium* or other important waterborne pathogens. It is especially important that sera samples collected during human volunteer studies be stored.

APPROACHES TO ESTIMATING THE RISK

Two approaches were described in detail at the workshop. One approach (waterborne attributable risk (AR%) – background AGI) uses information about the background levels of AGI from all causes and waterborne AGI risks to estimate the number of endemic cases associated with US public water systems (Colford *et al.* 2006; Roy *et al.* 2006). The other approach uses professional judgments about waterborne AGI risks, Bayesian statistics, and Monte Carlo

Table 5 | *Cryptosporidium* sero-prevalence levels in adult populations using public water systems with either surface or groundwater sources, US, 1998–2003 (Casemore 2006; Frost *et al.* 2002)

	Antibody (frequency of detection)			
	15/17 kDa		27 kDa	
Study site	Surface water	Groundwater	Surface water	Groundwater
Two cities in Northwest	21%	11%	31%	23%
Two cities in Southwest	49%	35%	55%	52%
Two cities in Midwest	54%	38%	54%	38%
Four cities in Midwest	72%	52%	83%	73%

analyses (Messner *et al.* 2006). Workshop participants also discussed how microbial risk assessments (MRAs) and disease surveillance data could help inform the estimates from these two approaches. Participants agreed that the use of all of these approaches and methods would help increase confidence in an estimate. Each should, however, present a confidence interval along with any point estimate of risk so that the estimates can be easily compared.

Waterborne Attributable Risk–background AGI approach

The information needed for this approach includes an estimate of waterborne AGI risks from appropriate epidemiologic studies, the background AGI risk, and the proportion of the population that is exposed (e.g. number of persons that drink tap water from public systems). Current information about endemic waterborne AGI risk (AR%) is available from several household-intervention studies. The background AGI risk is available from FoodNet and other studies in the United States (Roy *et al.* 2006). The rough estimate presented by Colford *et al.* (2006) illustrates this approach using assumptions about the estimated population consuming different sources of drinking water and the relative quality of the water sources under different scenarios.

To obtain a more precise estimate, requires information for both background and waterborne AGI risks for each of the population groups that are exposed to the various categories of tap water.

Recommendations

The FoodNet data can be used to provide a rough estimate of background AGI rates, since it covers approximately 13% of the population. However, additional information is needed to assess the variability in background AGI rates there is across the country. Workshop participants recommended that a meta-analysis be conducted for the various studies of AGI incidence or prevalence reported in the literature to assess the variation across various populations.

A more precise estimate requires additional information. The concern is how to identify the important water system characteristics and populations, and then how to obtain the risk estimates for each category of water system. Water systems serving the FoodNet studies could be defined by source and treatment and background rates of AGI could be determined for each water system category. Alternatively, a national study could estimate the populations that are exposed to various water sources and treatment. Whether additional studies should be conducted to determine water-source and treatment-specific risks depends largely upon the use of the national estimate.

Bayesian-Monte Carlo approach

This approach to estimating endemic waterborne AGI risks is based on expectations of risk from a panel of experts (i.e. their best professional judgment), Bayesian statistics, and Monte Carlo analyses to develop central tendency estimates and associated ranges of the national estimate. Two estimates were presented at the workshop using expert judgments of EPA staff; one was based on the attributable risk reported from the Canadian household-intervention study, and the other was based on the US household-intervention study (Messner *et al.* 2006). Workshop participants agreed the approach was useful.

Recommendations

Sensitivity analyses should be conducted for estimates using this approach. Additional estimates should be obtained periodically. In particular, the next estimate should be obtained with a non-EPA panel of experts who have a wide range of experience and expertise.

Microbial risk assessment (MRA)

Workshop participants agreed that MRAs could provide insight into a national estimate of AGI provided that appropriate data are available as input to MRA models. For example, MRA information can help address the relative importance of various waterborne pathogens that contribute to AGI. It should, however, be recognized that MRA-based estimates derived from pathogen-specific data will inherently under-estimate the total risk attributable to drinking water. This is because the total risk is a function of all pathogens present in drinking water, whereas the MRA

estimates will likely be based on data for several specific pathogens.

Recommendations

MRAs should be conducted for selected waterborne pathogens, and this information should be used to supplement the national estimate. Candidate pathogens include *Cryptosporidium*, *Giardia*, *E. coli* 0157:H7; norovirus, *Shigella*, and *Campylobacter*. These are the most frequently identified pathogens that cause waterborne outbreaks.

Estimate of waterborne risks from disease surveillance data

Disease surveillance data have been used to estimate the number of cases and severity of foodborne illness in the United States. For example, Mead *et al.* (1999) compiled and analyzed data from various disease surveillance systems and surveys to estimate both the total number of cases of AGI as well as cases attributable to foodborne exposures in the United States. Reported cases, hospitalizations, and deaths due to various etiologic agents, including AGI, were adjusted to account for under-reporting, and the proportion of illnesses specifically attributable to foodborne transmission was estimated.

Recommendations

Workshop participants suggested that an approach similar to that used by Mead *et al.* should be used to estimate waterborne illnesses. The CDC is currently collaborating with EPA to prepare such an estimate. The adequacy of this approach depends on good surveillance data and reasonable estimates for possible under-reporting of cases. Estimating the proportion of cases of each illness suspected to be waterborne will require professional judgment from a panel of experts.

IMPORTANT DATA GAPS

Workshop participants agreed that the current information is inadequate to assess AGI risks for various water system vulnerabilities (e.g. sources of contamination, types of water sources, and treatment effectiveness). Additional information is needed about the health risks, population exposures to water systems with the various vulnerabilities, and water usage and behavior (e.g. bottled water consumption, water usage away from home, groups that consume large amounts of water, use of tap water filters). This information is required to develop a more precise estimate of endemic risks.

Workshop participants identified the following important data gaps (Table 6) and recommended that future studies evaluate risks associated with the following exposures or population groups:

Sensitive subpopulation risks

Although some information is available about endemic waterborne risks for AIDS patients and persons of various ages, the information is insufficient to address infection and illness risks for sensitive subpopulations.

Distribution system risks

The national estimate can be thought of as the risk associated with pathogens that may be present in the water as it leaves the water treatment facility and the risk from pathogens that may be present in the water distribution system. Few studies have considered the endemic risk that may be associated with distribution system contamination (Payment *et al.* 1997; Hunter *et al.* 2005). Waterborne outbreaks associated with distribution system contamination have increased in importance in recent years, and endemic risks are likely associated with distribution system contamination (Craun *et al.* 2006*b*; LeChevallier *et al.* 2003).

Groundwater risks

Waterborne outbreaks continue to occur when groundwater is contaminated, but little is known about endemic risks. No epidemiologic studies have been conducted to assess the endemic waterborne risks that may be associated with wells in various aquifers, especially those in a karst aquifer. A significant number of people consume water from groundwater sources and it is important to assess the potential risks for this population.

Table 6 | Summary of workshop recommendations

Category	Recommendation
Definition of illness	EPA and CDC should recommend a standard definition of gastrointestinal illness for future studies.
Measures of risk	The statistical power of epidemiologic studies should be reported.
	Definitions and computations of attributable risk should be included in publications.
Illness burden	Estimates of risk should include one or more measures of illness severity.
	Possible long-term effects of waterborne diseases should be identified.
Waterborne disease outbreaks	Epidemic risks should be considered along with endemics risks.
	Studies should be done to estimate the degree of under-reporting of outbreaks.
Household-intervention trials	Sites for household-intervention studies should have highly challenged source water quality and treatment effectiveness.
Community-intervention studies	Community-interventions studies should focus on systems optimizing water treatment or changing disinfection practices.
	Sites should be large communities with unfiltered surface water or communities using groundwater under the direct influence of surface water.
Combined intervention studies	Community-intervention studies should consider nesting a household intervention within the study population
Case-control studies	A case-control study of gastrointestinal illness should be conducted if feasible.
Cohort study	Researchers should identify new or existing cohorts where an evaluation of drinking water risks could be added to the study.
Seroprevalence	More studies should be conducted to assess *Cryptosporidium* infection related to drinking water exposures.
	A repository of stored sera should be established to facilitate the conduct of serological studies as new methods for waterborne pathogens are developed.
Waterborne PAR-background AGI approach	A meta-analysis of gastrointestinal illness studies should be conducted to assess the variation of incidence or prevalence across populations.
Bayesian-Monte Carlo approach	Additional estimates should be considered using this approach.
	Expert panels should include members that may have differing opinions on risk.
	Sensitivity analyses for each analysis should be conducted and compared.
Microbial risk assessment	MRAs should be conducted for selected waterborne pathogens and used to supplement the national estimate.
Disease surveillance data	Approach similar to Mead *et al.* (1999) should be attempted for waterborne illness.

Individual water system risks

Although some information is available about endemic waterborne risks associated with individual systems, the national estimate does not consider risks associated with individual wells, bottled water, or other non-public water sources. A significant number of people consume water from these sources and it is important to assess the potential risks for this population.

Secondary transmission risks

Although some information is available about person-to-person transmission of infection and subsequent illness for waterborne pathogens, substantial uncertainty still exists regarding the magnitude of secondary transmission. Drinking water and person-to-person routes of exposure are not independent. Depending upon the pathogen, if more people are infected via drinking water there is more potential for person-to-person transmission. Secondary transmission risks may be an important contribution to the national estimate.

Development of a scheme to categorize water systems and exposures

Key attributes for the categorization of water systems need to be developed to compute an estimate of specific risks. Suggested attributes include source water type, watershed activities, water treatment, distribution system age, and water quality measures (e.g. turbidity, coliforms). As the database on attributable risk grows, the number of water systems this applies to will be critical to the computational effort for a national estimate.

Identification of etiologies

Very few studies of symptomatic AGI have made efforts to identify the specific pathogens responsible for these illnesses. Understanding these pathogens, their life cylces, survival characteristics, resistance to current water treatments, and sources is important. This knowledge will provide insight into variations of illness across communities that may be linked to differences in drinking water sources and treatment.

SUMMARY

Workshop participants agreed that data are available for a rough estimate of the endemic waterborne risks and that an estimate should be made at this time even if it is imprecise and uncertain. The assumptions and limitations should, however, be fully described. Additional estimates should be made using the approaches described above and the estimates should be compared. The estimates should consider the variability of risks across various water systems based on water source and treatment processes. Distribution system risks should also be considered. The analyses should be made available so that others can evaluate and comment on the approach and magnitude of the estimate. Examples of the approach and the current estimates are described in this special issue (Colford *et al.* 2006; Messner *et al.* 2006).

It is important that the current information from epidemiologic studies be interpreted with caution. Differences in risk observed in the various studies may be due to differences in water system vulnerabilities or drinking water quality, but they may also be related to methodological limitations of the study designs. It should also be remembered that public drinking water systems may not be the most important contributor to AGI risks, but the impact may be great because of the large number of people who may be affected. It is important that investigators design future studies with sufficient statistical power.

Fourteen key recommendations (Table 6) and eight important data gaps (Table 7) were identified in discussing

Table 7 | Major data gaps for assessing endemic drinking water risks in the United States

Important data gaps
Sensitive subpopulation risks
Distribution system risks
Groundwater risks
Individual water system risks
Secondary transmission risks
Identification of etiologic organisms causing endemic gastrointestinal illness
Plan to categorize water systems and waterborne exposures for US populations

the papers published in this special issue. These recommendations and data gaps serve as a blueprint for researchers interested in conducting further studies on waterborne disease and public health officials interested in continuing to make estimates of waterborne disease.

WORKSHOP PARTICIPANTS

Workshop participants were: Timothy J. Wade, US Environmental Protection Agency (EPA), Chapel Hill, NC; Michael Beach, Pat Lammie, Jeffrey Priest, Sharon Roy, Centers for Disease Control and Prevention, Atlanta, GA; Valerie Blank, Phil Berger, Michael Messner, Yu-Ting Guilaran, EPA, Washington, DC; Patricia Murphy, EPA, Edison, NJ; Glenn Rice, Mary Rothermich, EPA, Cincinnati, OH; David Casemore, University of Wales, Aberystwyth, Wales; John M. Colford, Jr., University of California, Berkeley, CA; Paul R. Hunter, University of East Anglia, Norwich, England; Jeffrey Soller, Soller Environmental, Berkeley, CA.

Invited but unable to attend was Jeffrey Griffiths, Tufts University, Boston, MA; however, Dr. Griffiths participated via a conference telephone call during one of the sessions.

DISCLAIMER

The views expressed in this article are those of the individual authors and do not necessarily reflect the views and policies of the US Environmental Protection Agency. The article has been subject to the Agency's peer review and approved for publication.

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