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Approaches to Estimating the Waterborne Disease Outbreak Burden in the United States: Uses and Limitations of the Waterborne Disease Outbreak Surveillance System

National Center for Environmental Assessment
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TABLE OF CONTENTS

TABLE OF CONTENTS cont.

Page

TABLE OF CONTENTS cont.

Page

TABLE OF CONTENTS cont.

Page

LIST OF TABLES

LIST OF TABLES cont.

LIST OF TABLES cont.

LIST OF FIGURES

LIST OF FIGURES cont.

LIST OF FIGURES cont.

LIST OF ABBREVIATIONS

AGI	Acute gastroenteritis illness of unknown etiology
AIDS	Acquired Immunodeficiency Syndrome
CAST	Council for Agricultural Science and Technology
CDC	Centers for Disease Control and Prevention
COI	Cost-of-illness
CPI	Consumer Price Index
DALY	Disability Adjusted Life Years
ER	Emergency room
HCUP	Health Care Utilization Project
PCG	Productivity losses of caregiver
PI	Productivity losses of ill person
PV	Physician visit
SDWA	Safe Drinking Water Act
SM	Self medication
SRSV	Small round structured virus
U.S. EPA	U.S. Environmental Protection Agency
VSL	Value of statistical life
WBDO	Waterborne disease outbreak
WBDOSS	Waterborne Disease Outbreak Surveillance System
WTP	Willingness-to-pay

PREFACE

This report was developed by the U.S. Environmental Protection Agency's (U.S. EPA) Office of Research and Development (ORD), National Center for Environmental Assessment in collaboration with researchers from Craun and Associates, Inc. It contains information concerning a waterborne disease outbreak database that has been jointly maintained by the Centers for Disease Control and Prevention (CDC) and the U.S. EPA since 1971. The document examines waterborne outbreaks from the perspective of disease burden. The term *disease burden* is a general expression that is used to capture the magnitude of the health impacts that occur; it generally refers to decrements in a population's health, but can include the associated economic burden. This effort supports research mandated by the Safe Drinking Water Act (SDWA) Amendments of 1996. Specifically, section 1458(d) requires the U.S. EPA and CDC to develop a national estimate of waterborne disease occurrence ("the national estimate"). This research also addresses the need for improved understanding of the impact of waterborne microbial risks in the U.S.

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EXECUTIVE SUMMARY

INTRODUCTION

The dramatic reduction in the incidence of waterborne infectious diseases brought about by the filtration and chlorination of public drinking water supplies and effective sewage treatment is one of the great public health achievements of the 20th Century. Although water treatment technologies and protection of water sources from sewage contamination are mandated in order to reduce the risk of waterborne disease in the U.S., outbreaks still occur.

Information about U.S. waterborne disease outbreaks (WBDOs) is voluntarily reported to the Waterborne Disease Outbreak Surveillance System (WBDOSS), which is maintained by the Centers for Disease Control and Prevention (CDC), the U.S. Environmental Protection Agency (U.S. EPA), and the Council of State and Territorial Epidemiologists. State, territorial and local public health agencies are responsible for detecting and investigating WBDOs and reporting them to this passive surveillance system. CDC and U.S. EPA evaluate the outbreak reports to assess the strength of the epidemiologic evidence implicating water and the available information about water quality, sources of contamination and system deficiencies. Information about the occurrence of WBDOs and their causes is published biennially in the *Morbidity and Mortality Weekly Report*. The illnesses that occur during these WBDOs can range from mild episodes of gastroenteritis to severe outcomes that can result in dehydrating diarrhea, chronic sequelae, hospitalization or death.

The purpose of this report is to estimate the burden of disease associated with the 665 WBDOs in the U.S. that were reported to the WBDOSS between 1971 and

2000 and were associated with infectious agents. In health economics, the term *burden of disease* refers to the composite impact of the number of cases, the cases' severity and, in some instances, the associated economic impacts.

LIMITATIONS OF THE WBDOSS FOR ASSESSING DISEASE BURDEN

An important limitation of the WBDOSS data set is that not all WBDOs and associated cases of illness are recognized or reported. The reported WBDO events and characteristics do not reflect the true number of outbreaks or incidence of disease, and the extent to which outbreaks are not recognized, not investigated or not reported is unknown. Whether an outbreak is reported depends on many factors including: (a) public awareness, (b) the likelihood that persons who are ill will seek treatment and consult the same health-care providers, (c) availability and extent of laboratory testing, (d) local requirements for reporting cases of particular diseases and (e) the surveillance and investigative activities of state and local public health and environmental agencies.

In addition, not all outbreaks are rigorously investigated, and information may be incomplete. Often the primary intent of an outbreak investigation is to determine the cause and to prevent additional illness; such investigations may not focus on identifying epidemiologic information or water quality data that are important in estimating the disease burden. Thus, our analyses cannot provide a burden estimate of the true incidence of waterborne outbreak illnesses in the U.S. population. Such an estimate would require additional data and procedures to estimate unreported outbreaks and unrecognized cases including unrecognized endemic cases. Furthermore, the WBDOSS does not include sporadic or endemic cases of waterborne illness. The reader should be mindful of these limitations when comparisons are made between

WBDOs that have occurred during different time periods, in different types of source waters, using different types of treatments attributed to different etiologic agents and as a consequence of various treatment deficiencies. Despite these limitations, the WBDOSS database does constitute the most comprehensive source of information on WBDOs in the U.S. and is useful for demonstrating our surveillance-based approach for analyzing the reported outbreak component of the infectious disease burden posed by contaminated drinking waters.

MEASURES OF THE BURDEN OF DISEASE

The approach used in this report to determine the burden of waterborne infectious disease outbreaks due to drinking water is illustrated in Figure ES-1. While a variety of measures, such as Disability Adjusted Life Years (DALYs), have been employed to estimate disease burden, we limit this analysis to the benefits assessment measures currently employed in U.S. EPA rulemaking procedures: epidemiologic measures and monetary measures. It is important to note that epidemiologic measures must be obtained or estimated in order to quantify the monetary burden. The monetary burden (expressed in year 2000 U.S. dollars) presented here is consistent with current U.S. EPA economic practices. The U.S. EPA evaluates the monetary burden associated with mortality using the “value of a statistical life” (VSL), which is based on willingness to pay approaches for estimating the economic value of reducing the risk of premature death. To estimate the monetary burden associated with the morbidity from waterborne illnesses, U.S. EPA uses cost-of-illness (COI) estimates. For the WBDO analysis, we employed data derived from several peer-reviewed sources that provide COI estimates specifically for waterborne outbreaks.

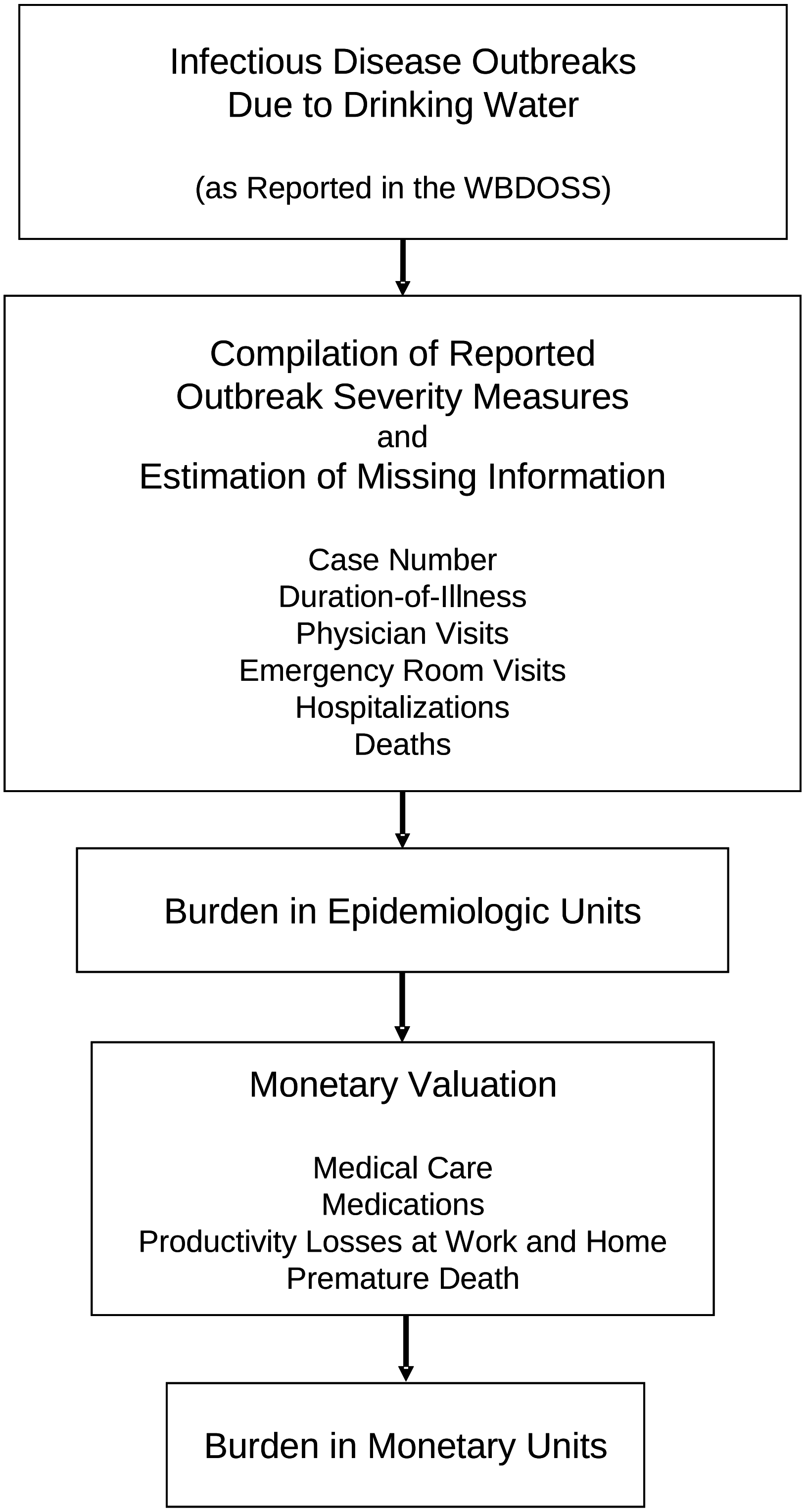

FIGURE ES-1

Methodology to Determine the Disease Burden of WDBOs

METHODS USED TO ESTIMATE THE EPIDEMIOLOGIC BURDEN

Table ES-1 summarizes the information available for the 665 infectious WBDOs reported during 1971-2000. When essential information about illness severity characteristics was inadequately reported for disease burden estimation purposes — either because the information was not requested on CDC 52.12 (i.e., the form investigators use to report outbreaks to the WBDOSS) or the form was incompletely filled out — we estimated values necessary for our analyses. If available, we used information from other WBDOs in the database that were attributed to the same or a similar etiologic agent. If sufficient information was not available from other WBDOs, information was obtained from the scientific and medical peer-reviewed literature. Some 45% of the WBDOs (n=300) were attributed to specific waterborne pathogens that were identified in clinical specimens obtained from the case patients. The other 365 outbreaks were identified as "acute gastrointestinal illness of unknown etiology" (AGI) either because laboratory results were not reported or an etiologic agent could not be identified by the tests performed.

EPIDEMIOLOGIC BURDEN MEASURES

The summary epidemiologic severity measures used for the epidemiologic burden analysis are presented in Table ES-2.

Duration of Illness

By multiplying the average duration of illness and the number of cases, we estimated person-days ill associated with each WBDO. This measure provides a succinct way to compare the population-level health impact of different diseases. For example, the public health impact of a norovirus (2-day typical duration of illness)

TABLE ES-1

Availability of Severity Measures in the WBDO Surveillance System (Number of Infectious or Suspected Infectious Drinking Water Outbreaks = 665)

Severity Measure	WBDOs for Which Severity Measure was Reported		Does CDC 52.12 Request this Measure?
	Number	Percent	
Cases of Illness	665	100	Yes
Duration of llness	282	42	Yes
Hospital admissions	659	99	Yes
Physician visits	29	4	No
Emergency room visits	15	2	No
Deaths	665	100	Yes

TABLE ES-2

Epidemiological Burden Measures Used in the Burden Analysis

Burden Measure	Value Used	Reported or Estimated
Cases	569,962	Reported
Person-Days Ill	4,504,933	Calculated from reported case numbers and reported or estimated durations of illness
Physician Visits	41,985	Estimated
Emergency Room Visits	23,575	Estimated
Hospitalizations	5,915	Reported
Deaths	66	Reported

outbreak of 50 cases could be compared to the public health impact of a *Giardia* (12-day typical duration of illness) outbreak of eight cases: 100 person-days ill for the norovirus outbreak, 96 person-days ill for the *Giardia* outbreak.

Physician and Emergency Room Visits

Form CDC 52.12 does not include information about the number of physician and emergency room visits. When available, we used the physician-visit rate reported in the WBDOSS for the same etiologic agent to estimate unreported rates. For emergency room visits, most estimates were based on the pathogen group rather than a specific pathogen because of sparse information. We estimated visits only for WBDOs in which the number of hospitalizations constituted fewer than 75% of the reported illnesses. For WBDOs where hospitalizations were greater than 75%, we assumed the severity of the illnesses resulted in few cases treated on an outpatient basis. Both estimates are based upon very few reported values and we were unable to locate peer-reviewed literature for alternative estimates. Thus, these components of the burden estimate are highly uncertain.

Hospitalizations and Deaths

Form CDC 52.12 requests the number of cases hospitalized and deaths occurring during an outbreak. All WBDO reports included an entry for deaths and 659 of the reports (99%) included hospital admission information. We address the possible under- or over-reporting of these measures by comparison of the WBDOSS data to other infectious disease epidemiologic data available from published literature sources.

EPIDEMIOLOGIC BURDEN ESTIMATES

To examine characteristics or circumstances that may be associated with the cause of a WBDO and the magnitude of its burden, we analyzed the epidemiologic data by summarization within five categories of factors potentially relevant to the causation of a WBDO: etiologic agent (i.e., the pathogen), water system type, water system deficiency, time period and water source type. Due to the overwhelming influence of the 1993 Milwaukee cryptosporidiosis WBDO, we also developed comparisons of the impact of the various factors excluding the data from this event. This WBDO occurred in a community water system that used surface waters as a source water and the outbreak was attributed to the protozoan, *Cryptosporidium*, that occurred in the drinking water due to a treatment deficiency. This WBDO contributed 403,000 (71%) cases of illness, 3,627,000 (81%) person-days ill, 20,280 (48%) physician visits, 11,727 (50%) emergency room visits, 4400 (74%) hospitalizations and 50 (76%) deaths to the estimated epidemiologic burden.

Epidemiologic Burden by Etiologic Agent

Protozoa, primarily *Cryptosporidium* and *Giardia*, were associated with the most cases, person-days ill, physician visits, emergency room visits, hospitalizations and deaths (Table ES-3). The Milwaukee WBDO accounts for more person-days ill, emergency room visits, hospitalizations and deaths than all other WBDOs combined. Excluding the Milwaukee WBDO, protozoan WBDOs still account for more person-days ill and physician visits than WBDOs caused by viruses or bacteria. However, bacterial WBDOs account for more hospitalizations and almost all of the deaths that were not associated with cryptosporidiosis.

TABLE ES-3

Epidemiologic Burden of Reported Infectious Waterborne Outbreaks in Drinking Water by Etiologic Agent Type, 1971 to 2000

Etiologic Agent Type	Outbreaks	Cases	Person-Days Ill	Physician Visits	Emergency Room Visits	Hospital-izations	Deaths
AGI	365	83,493	265,120	8,822	9,426	378	1
Viruses	56	15,758	53,697	2,017	124	92	0
Bacteria	101	20,786	95,615	1,196	931	928	15
Protozoa							
Milwaukee WBDO	1	403,000	3,627,000	20,280	11,727	4,400	50
All Other WBDO	142	46,925	463,423	9,669	1,366	117	0
Total	665	569,962	4,504,854	41,985	23,575	5,915	66

Epidemiologic Burden by Water System

The most cases (485,844, 85% of total), person-days ill (4,215,965, 93% of total), physician visits (32,400, 77% of total), emergency room visits (16,268, 69% of total), hospitalizations (4,931, 83% of total) and deaths (62, 94% of total) were reported for WBDOs occurring in community water systems. If the Milwaukee WBDO data are excluded from the analysis, WBDOs occurring in community systems had 50% of the total non-Milwaukee cases, 67% of the person-days ill, 55% of the physician visits and 75% of the deaths. WBDOs occurring in non-community systems involved 57% of the total non-Milwaukee emergency room visits and 58% of the hospitalizations. The WBDOs that occurred in individual water systems accounted for no more than 3% of any of the measures when Milwaukee data were included and no more than 7% with Milwaukee excluded.

Epidemiologic Burden by Source Water

WBDOs in surface water systems were reported less frequently than in groundwater systems but resulted in a greater number of cases (457,310), person-days ill (4,058,221), physician visits (29,735), emergency room visits (14,443), hospitalizations (4,644) and deaths (50). Most surface water outbreaks were associated with *Giardia* (48%) or AGI (36%), but most of the person-days ill in surface water outbreaks were associated with *Cryptosporidium* primarily due to the Milwaukee WBDO. AGI outbreaks were responsible for 62% of groundwater outbreaks and 52% of the person-days ill in these systems.

Epidemiologic Burden by Water System Deficiency

In comparison to the other water system deficiency issues, WBDOs associated with one or more water treatment deficiencies made the greatest contribution to the epidemiologic burden: 92% of the cases, 83% of the person-days ill, 87% of the physician visits, 86% of the ER visits, 84% of the hospitalizations and 79% of the deaths. Distribution system deficiencies and untreated groundwater accounted for all but about 2% of the remaining burden from each of the severity measures. If the Milwaukee WBDO data are excluded, water treatment deficiencies account for 70-75% of the non-Milwaukee cases, person-days ill, physician visits and emergency room visits, but only 38% of the hospitalizations and 13% of the deaths. Distribution system deficiencies were associated with 75% of the non-Milwaukee deaths and 13% of the hospitalizations. Untreated groundwater was the major contributor to the non-Milwaukee hospitalization burden with 40% of the hospital admissions.

Epidemiologic Burden by Time Period

The fewest number of WBDOs were reported in the 1990s, however that decade experienced the majority of the disease burden in all measured categories. WBDOs in the 1990s accounted for the most cases (432,195), person-days ill (3,775,241), physician visits (23,412), emergency room visits (13,834), hospitalizations (4735) and deaths (59). However, when the Milwaukee WBDO is excluded, the reported number of outbreaks, cases, person-days ill, physician visits, emergency room visits and hospitalizations decreases in each successive decade.

ECONOMIC BURDEN MEASURES AND METHODS

Figure ES-2 shows the components quantified to calculate the monetary burden associated with reported WBDOs. The results of the COI and VSL analyses were combined to estimate the monetary burden. Although both measures are expressed in monetary units, it should be noted that the COI measures capture only a subset of the factors that WTP measures capture. The COI estimates do not include averting behavior costs or defensive expenditures (e.g., purchasing a water filter or bottled water), costs of epidemiologic investigation or litigation, nor did they consider anxiety, pain and suffering. COI measures also do not capture costs associated with chronic disease or lost leisure time.

The COI measures direct and indirect costs. The direct medical costs include medication, physician visits, emergency room visits and hospital stays. Lost productivity, an indirect cost, is estimated based on a fraction of the duration of illness. The COI of the j^{th} outbreak can be calculated using the mean values of direct and indirect costs reported in other outbreaks (see Equation ES-1).

$$COI_j = SM_j + PV_j + ER_j + H_j + PI_j + PCG_j \qquad \text{(Eq. ES-1)}$$

where:

SM_j = Total cost of self medication purchased to treat illness associated with the j^{th} outbreak (2000$)[1]

PV_j = Total cost of physician visits associated with the j^{th} outbreak (2000$)

[1] All cost estimates are adjusted to 2000 U.S. dollars (2000$) using the consumer price index (CPI) for medical services. The CPI is the average change in prices over time for a market basket of goods and services (in this case medical goods and services such as prescription drugs and medical supplies, physicians' services and hospital services) allowing comparisons using constant monetary units.

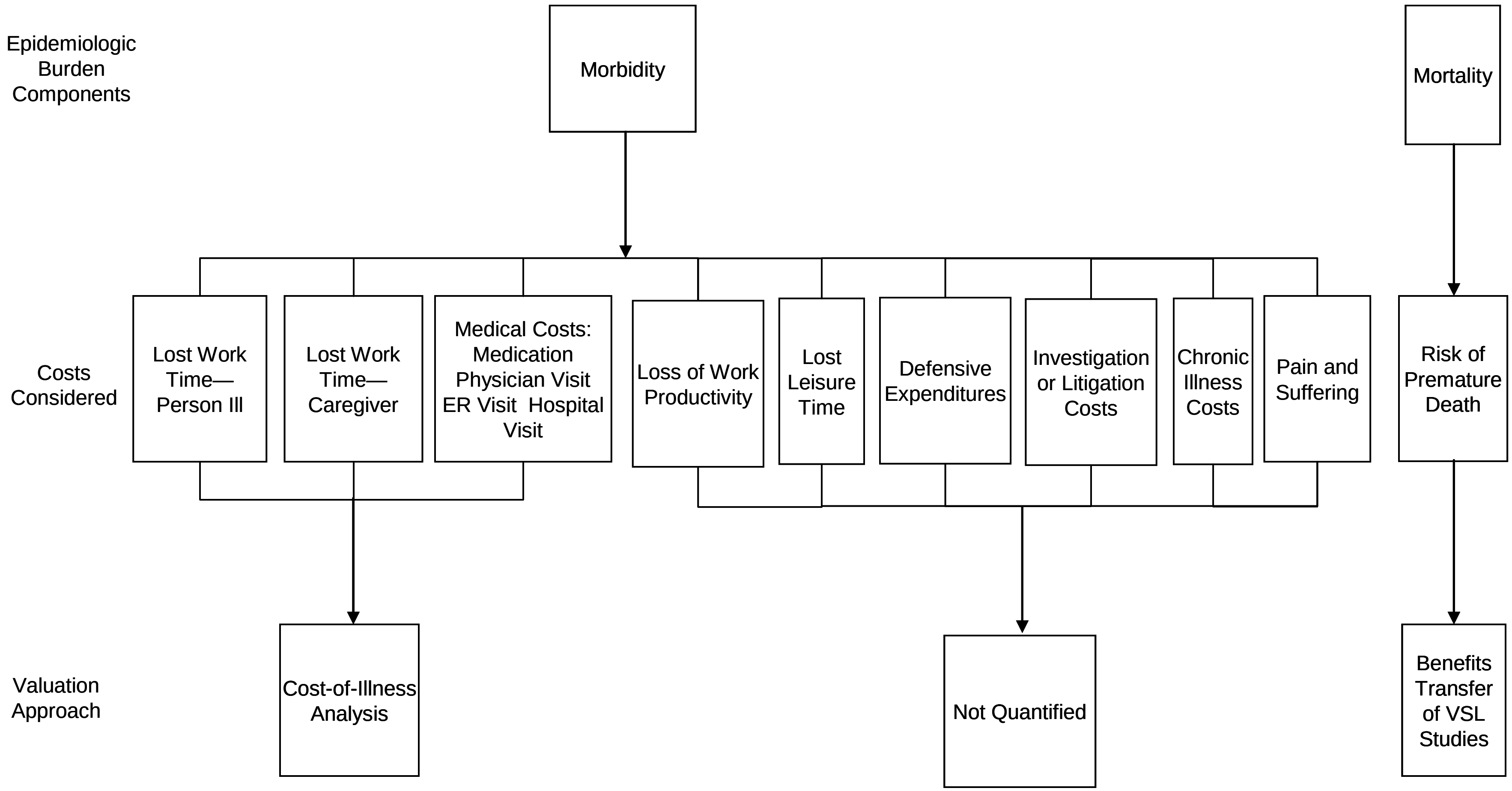

FIGURE ES-2

Components of the Monetary Burden

ER_j = Total cost of emergency room visits associated with the j^{th} outbreak (2000$)

H_j = Total cost of hospitalizations associated with the j^{th} outbreak (2000$)

PI_j = Productivity losses of ill persons associated with the j^{th} outbreak (2000$)

PCG_j = Productivity losses of caregivers associated with the j^{th} outbreak (2000$)

By using estimated mean values for the morbidity costs, this equation does not capture important sources of cost variability among cases and across different outbreaks. The definitions and calculations from Equation ES-1 are based largely on an economic analysis of the 1993 Milwaukee *Cryptosporidium* outbreak by Corso et al. (2003). The majority of COI measures were estimated using illness severity indicators acquired from a telephone survey of Milwaukee residents (Mac Kenzie et al., 1994) and data provided by the medical and financial records of 11 hospitals in Milwaukee (Corso et al., 2003). In the economic burden analysis, we assumed that medical treatment administered and costs for gastrointestinal illnesses have remained constant across years. All cost estimates were updated to 2000 dollars using the Consumer Price Index for various categories of medical care.

Because the WBDOs reported in the surveillance system do not identify cases of illness by severity categories of mild, moderate and severe (as used in the Corso et al. [2003] Milwaukee WBDO economic analysis), we use surrogate measures (physician visits and emergency room visits comprised moderately ill cases while hospitalizations and deaths comprised severely ill cases). This introduces additional uncertainty into the COI estimates.

Cost of Self Medication (SM)

For a WBDO, the cost of SM is the total cost of over-the-counter medications for mild, moderate and severe illness (e.g., anti-nausea, anti-diarrheal medications and electrolyte replacement therapy).

Cost Associated with Physician Visit (PV)

The costs associated with a physician visit include the professional fee and any prescribed medication but not SM cost.

Cost Associated with Visiting an Emergency Room (ER)

The cost of an ER visit includes the costs of the ER, attending physician, ambulance and prescribed medication. If an ER visit results in a hospital admission, then the visit is also counted as a hospitalization.

Cost Associated with Hospital Stay (H)

Hospitalization costs are based on the 1997 Nationwide Inpatient Sample data by Health Care Utilization Project (HCUP, 1997). Individual discharges were selected for examination of costs related to particular diseases based on the occurrence of specific International Classification of Diseases, Ninth Revision (ICD-9) codes among the first three diagnoses listed on the hospital discharge report. Observations were analyzed for specific pathogens and groups of pathogens, and the Health Care Utilization Project reported the total hospitalization charges for selected pathogens or categories. For the final cost estimates, we multiplied the hospital charges by the national case-weighted cost-to-charge ratio of 0.4.

Cost Due to Loss in Productivity

Productivity losses potentially have two components: complete days lost and lost productivity while working (i.e., reduced hours or working at less than full capacity). We only calculated the value of a complete day lost. Productivity losses from lost time at work and lost work at home due to illness were considered for

- Ill person who recovers
- Caregiver(s) for ill person

The wage components included salary income, overtime pay, bonus pay and self-employment earnings. Fringe benefits included health insurance and retirement pay. Household production included a number of valued activities, such as cleaning, cooking, home and auto maintenance, child care and child guidance, for which individuals are typically not compensated.

Value of Statistical Life

The value associated with a premature death due to a WBDO was based on a mean VSL estimate developed by U.S. EPA (2002a).

THE MONETARY BURDEN OF WBDOs

We estimated the monetary burden (2000$) of premature mortality associated with the WBDOs to be valued at approximately $424 million (Table ES-4). The morbidity monetary burden is estimated to be approximately $186 million. The largest morbidity cost is lost productivity of the ill person (66% of the total COI).

We combined morbidity and mortality measures into a single metric (i.e., dollars) and make a number of comparisons not easily accomplished with epidemiologic measures. However, the comparisons are greatly influenced by the large monetary

TABLE ES-4

Monetary Burden of Infectious Waterborne Disease Outbreaks, 1971-2000

Burden Measure	Monetary Burden	Percent
Self Medication	$1,272,000	Less than 1
Physician Visits	$2,708,000	Less than 1
Emergency Room Visits	$9,006,000	2
Hospitalizations	$29,936,000	5
Productivity Losses of Ill Persons	$123,357,000	20
Productivity Losses of Caregivers	$19,721,000	3
Total COI (Morbidity)	$186,000,000	30
Value of Statistical Life (Premature Death)	$424,380,000	70
Total	$610,380,000	100

burden associated with mortality. We present comparisons of the monetary burden by the same five summary categories considered for the epidemiologic analyses.

Monetary Burden Estimate by Etiology

Protozoan agents account for most of the monetary burden (Table ES-5), and *Cryptosporidium* is the major contributor to the overall monetary burden (76%). *Giardia* contributed 2% of the total monetary burden, but if the Milwaukee WBDO data are excluded from the analysis, *Giardia* would contribute 9%. Non-typhoid *Salmonella* spp. account for approximately 44% of the monetary burden attributed to bacterial pathogens. If the Milwaukee WBDO is excluded from the analysis, then the monetary burden associated with the bacterial WBDOs ($105 million) and AGI WBDOs ($22 million) would rank higher than the protozoan WBDOs ($19 million).

Monetary Burden by Water System Type, Water Treatment Deficiency and Time Period

Community systems had the largest monetary disease burden, 13 times larger than the burden associated with non-community systems. Water treatment deficiencies were the most important contributors to the monetary burden. The next two most important contributors were distribution system deficiencies and the use of untreated, contaminated groundwater. If the Milwaukee WBDO is excluded from the analysis, then distribution system deficiencies become the most important contributor to the monetary burden. Although the fewest number of WBDOs occurred during the 1990s, that decade dominates the monetary burden because the Milwaukee WBDO occurred in 1993. The monetary burden associated with WBDOs in the 1990s is more than 10 times the monetary burden estimate of either the 1970s or the 1980s. If the Milwaukee

TABLE ES-5 Monetary Burden, by Etiology (Pathogen Group)	
Etiologic Agent Group	Monetary Burden (2000$)
AGI	$21,537,000
Viruses	$3,252,000
Bacteria	$105,225,000
Protozoa	$480,366,000*
Total	$610,380,000

* Monetary Burden of Milwaukee WBDO - $461,148,000 or 96% of total monetary burden for Protozoa.

WBDO is excluded, the monetary burden in the 1990s is comparable to the estimates from the 1970s and 1980s.

Monetary Impact of the Milwaukee WBDO

The Milwaukee WBDO accounted for 76% of the overall monetary burden or approximately $461 million. The relative importance of morbidity measured by COI and mortality measured by VSL is similar whether Milwaukee is included or excluded from the analysis. This WBDO affected morbidity components by decreasing the relative importance of caregiver productivity losses, physician and ER visits and increasing the importance of productivity losses and hospitalizations in the total morbidity monetary estimate.

SENSITIVITY ANALYSES

We conducted three sensitivity analyses to evaluate key assumptions used to develop the monetary burden estimates and to examine the influence of model input parameters on these predictions. We note that these analyses do not address the under-reporting or over-reporting possibly associated with WBDOs.

Sensitivity Analysis 1

We estimated the difference in epidemiologic burden measure needed to cause a 5% change in the total monetary burden (Table ES-6). The total monetary burden was most sensitive to differences in the number of deaths and person-days ill; a change of only 8% in reported mortality (five deaths) changes the total monetary burden by 5%. A 21% change in the number of person-days ill causes a 5% change in the total monetary burden. When the Milwaukee WBDO is excluded, the total monetary burden also was most sensitive to differences in the number of deaths (6% change required)

TABLE ES-6

Percent Change Required in the Epidemiologic Burden to Change Monetary Burden Estimate by 5%

Epidemiological Burden Measure	WBDOSS-Reported Epidemiologic Measures	Change in the Projected Epidemiologic Measure Required to Cause a 5% Change in the Total Monetary Burden	Percent Change in Epidemiologic Measure Required to Cause a 5% Change in the Total Monetary Burden
Deaths	66	5	8%
Person-Days Ill	4,504,854	960,962	21%
Hospitalizations	5,915	6,031	102%
Emergency Room Visits	23,575	79,894	339%
Physician Visits	41,985	473,193	1,127%

and person-days ill (26% change required). The sensitivity of total monetary burden to relatively small changes in the number of deaths is due to the large value associated with reducing the risk of premature death (i.e., VSL) relative to the markedly smaller estimates developed for the morbidity costs.

Sensitivity Analysis 2

The monetary burden for premature death is based on a central tendency estimate for the number of premature deaths associated with WBDOs and the VSL value. For each pathogen, we developed plausible ranges for the number of deaths linked to WBDOs. We then described an existing distribution for the VSL from previous U.S. EPA analyses and used a Monte Carlo approach to predict a range of monetary burden estimates for these deaths. The purpose of this analysis was to identify the primary sources of uncertainty and to develop a plausible distribution of the monetary burden associated with deaths in the WBDOs. In the analysis, the number of deaths predicted ranges from 63 to 169. The mean of the distribution is 108 deaths and the 10^{th} and 90^{th} percentile values are 88 and 129 deaths, respectively. The predicted mean estimate of the monetary disease burden associated with deaths attributed to WBDOs is \$684 million; 10^{th} and 90^{th} percentile values are \$167 million and \$1.3 billion, respectively.

Based on rank correlation coefficient analysis, nearly all of the model output variability can be explained through the distribution of the VSL. The monetary analysis is affected primarily by the shape of the VSL distribution; however, the right skew of the upper-bound estimates of WBDO deaths also affected the predicted results.

Sensitivity Analysis 3

Although premature mortality accounts for 70% of the burden associated with the Milwaukee outbreak, the COI estimate for this WBDO accounts for over 75% of the total COI estimate for all 665 WBDOs. The third sensitivity analysis examined the impact of changes in two epidemiologic burden components, case number and illness duration, on the monetary burden estimate. Although not as influential as changes in the number of deaths, case number and illness duration accounted for much of the monetary burden associated with those WBDOs, which had no fatalities reported.

We developed several estimates of both the number of cases of illness that occurred during the Milwaukee WBDO and their average duration, and examined the influence of these alternative estimates on the associated monetary disease burden estimated for this WBDO. The Milwaukee WBDO contributed a considerable portion of the total number of person-days ill to this WBDO burden analysis. While the large estimated case number (403,000) is one aspect of the person-days ill burden, the magnitude of this component is also influenced by the duration-of-illness value. The outbreak investigation involved three different surveys, and each group was characterized by different mean and median illness durations (Table ES-7). Because information was not available to estimate the number of cases associated with each duration, our analyses compared a 3-day duration for all cases with a 9-day duration for all cases. Nine days is the typical duration of illness reported in the CDC fact sheets for cryptosporidiosis and is also the median of the median durations listed for all 12 *Cryptosporidium* WBDOs reported to the WBDOSS. Among these 12 WBDOs, the median duration ranged from 3 to 74 days.

TABLE ES-7

Duration of Illness, Milwaukee *Cryptosporidium* Outbreak Analysis of Mac Kenzie et al. (1994)

Population Surveyed	Duration (Days)			Survey Information (number of cases)
	Median	Mean	Range	
Laboratory-Confirmed Cases	9	12	1-55	285 (*Cryptosporidium* positive)
Clinical Infection	3	4.5	1-38	201 watery diarrhea
Household Survey	3	-	1-45	436 watery diarrhea

For the sensitivity analysis, we assumed the average duration of illness in the Milwaukee WBDO was alternatively 3 or 9 days. If a 3-day duration of illness were used instead of a 9-day duration, the monetary burden of morbidity would decrease by approximately one-half.

CONCLUSIONS

We demonstrate a methodology for assessing the disease burden associated with waterborne outbreaks. Our methodology, which relies on the examination of the WBDO surveillance data, provides additional insight for evaluating the overall burden of waterborne disease in the U.S. The analyses provide a plausible range of estimates of the disease burden of reported waterborne outbreaks from the time period 1971-2000, emphasizing the importance of mortality that may be associated with WBDOs. These analyses include an examination of disease severity and the costs associated with various waterborne pathogens and water system characteristics. This methodology also illustrates the limitations of using this passive surveillance system and reinforces the importance of collecting more detailed epidemiologic data to aid future disease burden efforts. We recommend that additional sensitivity analyses examine the effect that alternative assumptions might have on the disease burden estimates presented here. This could help identify the components that have the greatest potential impact on disease burden and could further delineate specific research needs for the future.

Although we estimate the burden associated with reported WBDOs, the primary limitation of the analyses was the inability to determine the potential impact of unrecognized and unreported WBDOs. Additional studies should attempt to estimate the number and type of WBDOs that may be unrecognized. We also provide several recommendations in the collection and reporting of WBDO surveillance data for the purpose of improving future burden estimates.

1. INTRODUCTION

The incidence of devastating waterborne infectious diseases such as cholera and typhoid was dramatically reduced in the United States after filtration and chlorination of drinking water was introduced around 1900. Widespread adoption of these water treatment technologies, as well as improved wastewater management, has been among the great public health achievements of the 20th Century (Cutler and Miller, 2005). However, waterborne disease outbreaks (WBDOs) do still occur in the U.S., with hundreds to thousands of cases of illness attributed to these events every year. Between 1991 and 2002, the average annual number of drinking water outbreaks reported in the U.S. was 17 – only slightly fewer than the annual average of 23 reported throughout 1920-1930 (Craun et al., 2006a).

Since 1971, the Centers for Disease Control and Prevention (CDC), the U.S. Environmental Protection Agency (U.S. EPA), and the Council of State and Territorial Epidemiologists have maintained the Waterborne Disease Outbreak Surveillance System (WBDOSS).[1] State, territorial and local public health agencies are responsible for detecting and investigating WBDOs and voluntarily reporting them to the CDC, which publishes biennial epidemiologic information on the occurrence and etiology of U.S. WBDOs (e.g., Barwick et al., 2000; Lee et al., 2002). In the WBDOSS, the apparent cause of a reported WBDO is classified into one of five water system categories: (1) water treatment deficiency, (2) distribution system deficiency, (3) untreated groundwater, (4) untreated surface water, or (5) unknown or miscellaneous deficiency.

[1] "The unit of analysis for the WBDO surveillance system is an outbreak, not an individual case of a waterborne disease. Two criteria must be met for an event to be defined as a drinking water-associated disease outbreak. First, >2 persons must have experienced a similar illness after exposure to water." (Blackburn et al., 2004)

Since 1981, the lack of or inadequate water treatment as the cause of WBDOs has been reported with decreasing frequency over time, while distribution system deficiencies have been reported more frequently (Craun et al., 2006b).

When a WBDO occurs, individuals and communities incur both health and economic impacts. The health impacts can include a broad range of effects from the very mild (such as brief episodes of diarrhea in healthy adults) to severe (such as dehydrating and life-threatening diarrhea in infants or the immunocompromised). The economic impacts can include the costs associated with treatment of the ill as well as lost productivity at work or home. Often in the health policy and health economics literature a composite measure of morbidity and mortality – and in some cases, economic impact – is assessed and expressed in a single metric that captures all the components. Such an assessment is frequently referred to as the *burden of disease* (Murray and Lopez, 1996; Gold et al., 1996). In general, burden of disease analyses consist of two steps: a thorough evaluation of the epidemiologic data describing the illnesses and an analysis that evaluates the health effects in terms of their impacts on the ill and society as a whole (Murray and Lopez, 1996).

1.1. PURPOSE AND POTENTIAL USEFULNESS OF A BURDEN OF WBDO ANALYSIS

The purpose of this WBDO analysis is not to provide an estimate of the true incidence and burden of outbreak-related waterborne illnesses in the U.S. (which would require additional data and procedures to estimate unreported outbreaks and unrecognized cases). Rather, the purpose here is to provide a summary of 30 years of WBDOSS information in terms of disease burden measures that are developed from surveillance data. As such, this analysis provides insight only into the public health and economic impact of the waterborne outbreaks and cases of illness that were reported to the WBDOSS. The methods developed here may provide valuable tools for future, more extensive, U.S. EPA waterborne disease burden analyses, and serve to supplement risk assessment methodology and intervention study approaches to overall burden estimation.

Economic analysis has become an integral part of the policy and rule-making process of federal agencies. The Safe Drinking Water Act (SDWA) not only mandates various actions to improve the microbiological quality of water in the U.S., the 1996 amendments also require that benefit-cost analysis be publicly available for new federal water quality regulations.[2] To date, economic analyses have been conducted for several major rules that target water quality issues that affect endemic levels of waterborne disease. Among these are the Long Term 1 and 2 Enhanced Surface Water Treatment Rules that focus on cryptosporidiosis incidence and the Groundwater Rule that focuses on viral illness incidence.[3] Benefit-cost analyses in this context require an estimate of the epidemiologic burden of waterborne disease characteristic of the water source under consideration. The disease burden analyses for these rules used risk assessment methodology (i.e., exposure characterization integrated with a dose-response relationship) to develop estimates of disease incidence in the U.S. population; illness severity distributions and mortality rates for representative illnesses (i.e., cryptosporidiosis and viral diseases) were drawn from a variety of non-waterborne-specific epidemiologic studies, surveillance records, and the medical microbiology

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[2] SDWA [104/1412(b)(3)(C)] (see http://www.epa.gov/safewater/sdwa/theme.html); Executive Order 12866 (see http://www.whitehouse.gov/omb/inforeg/riaguide.html).
[3] For more details on these water treatment rules, see http://www.epa.gov/safewater/standards.html.

literature. In contrast, this burden of WBDO analysis utilizes a surveillance database for the estimates of disease incidence and, in so far as possible, severity and mortality information specifically associated with the cases of illness recorded in the database. We hope this surveillance-based burden estimation methodology for WBDOs will prove to be a valuable addition to risk assessment methodology for future determinations of the total burden of waterborne disease in the U.S.

1.1.1. Objectives. The primary objective of this report is to demonstrate an approach for developing a burden of disease estimate that is based on surveillance data. To illustrate our approach, we use the reported information in the WBDOSS to develop a preliminary estimate[4] of the infectious disease burden associated with the illnesses recorded in the WBDOSS for outbreaks that occurred over the 30-year period of 1971 through 2000. Methods were devised to estimate necessary values for incompletely reported information in the database (see Chapter 2). The secondary objective is to compare WBDO burden estimates across etiologic agents, source water types, treatment deficiencies, and other outbreak characteristics.

Epidemiologic and monetary measures are provided here for burden estimation. The epidemiologic measures, which are essential for developing the monetary burden, include the following components:

- Cases of illness
- Duration of illness
- Physician visits

[4] The estimate is considered preliminary because it is based solely on outbreaks (and the cases of illness within those outbreaks) that are reported to the WBDO surveillance system. A comprehensive assessment would require estimates of both the unrecognized outbreaks and unreported cases as well as an assessment of possible over-estimates of cases in the surveillance system. These additional levels of analysis are not provided in this report.

- Emergency room visits
- Hospitalizations
- Deaths.

The monetary measures consider:

- Cost of medical care
- Cost of prescribed medication and self medication
- Productivity losses at work and home
- Value of a statistical life.

The monetary burden (expressed in U.S. dollars) uses cost-of-illness (COI) and willingness-to-pay (WTP) approaches that are consistent with current U.S. EPA economic practices (U.S. EPA, 2000a). Further discussion of these approaches is presented in Sections 1.4 and 1.5.

The burden estimates presented in this report do not include endemic (i.e., sporadic) cases of waterborne illness unrelated to specific outbreak events nor do they include cases of acute chemical poisonings associated with drinking water. The approach used in this report to determine the burden of waterborne infectious disease outbreaks due to drinking water is illustrated in Figure 1-1.

1.2. THE WBDO SURVEILLANCE SYSTEM

The outbreak data considered in this report are obtained from the WBDOSS database and are limited to WBDOs reported from 1971 to 2000. Although reporting of outbreak information to the CDC is voluntary, the CDC does provide a standard form (CDC 52.12) for that purpose. Appendix A includes the various versions of CDC 52.12

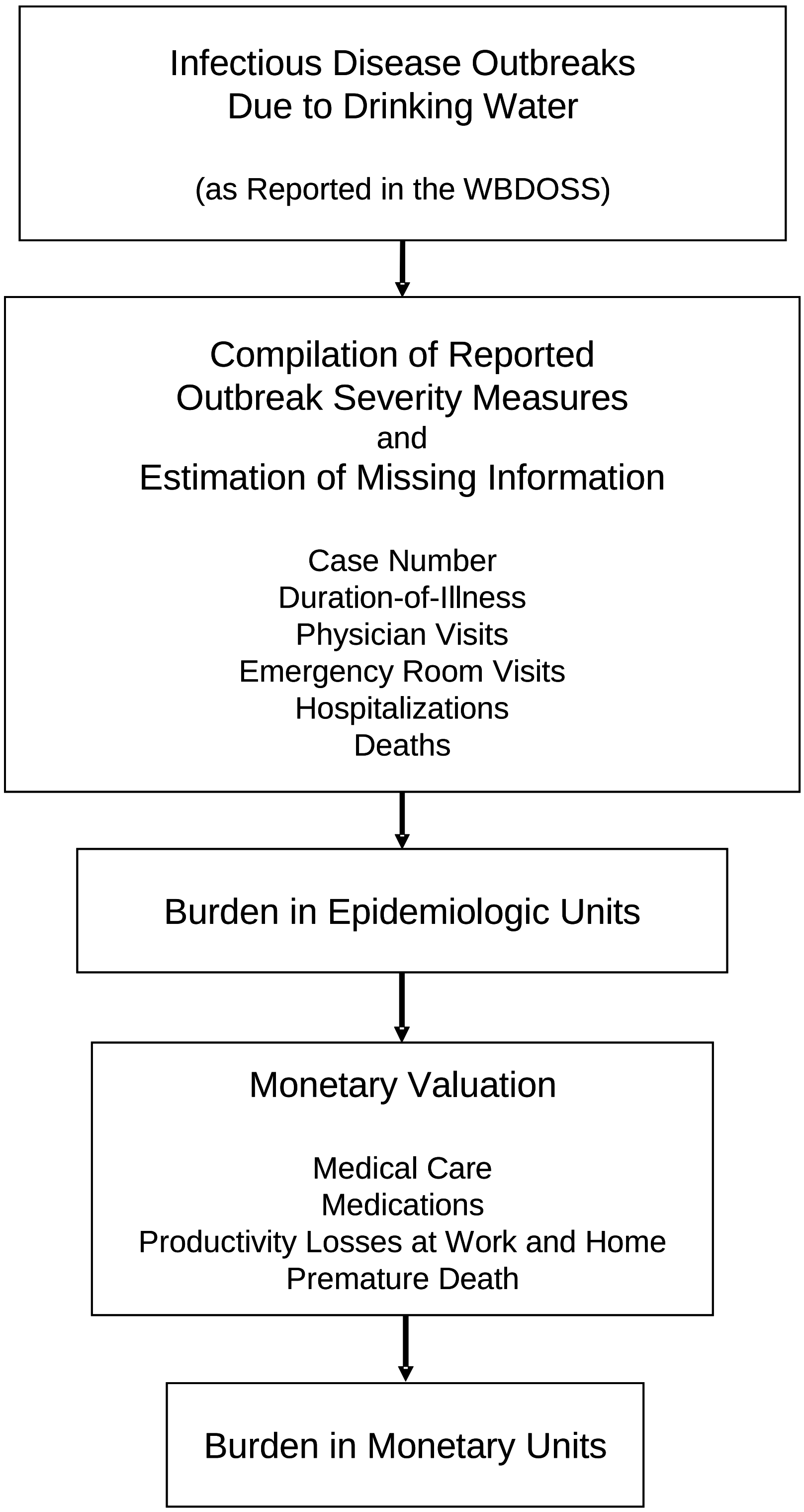

FIGURE 1-1

Methodology to Determine the Disease Burden of WBDOs that have been used from 1971-2000[5] as well as a detailed description of the surveillance system. The purpose of the WBDOSS is to record the data needed to appraise and periodically report the causes of WBDOs (e.g., etiologic agents, water system deficiencies, and sources of contamination) and the resulting cases of illness. These data can be used to evaluate the adequacy of technologies for providing safe drinking water, and to indicate research priorities that can lead to improved water-quality regulations. This system provides the primary source of data concerning the scope and effects of reported waterborne disease outbreaks in the U.S.

A burden of disease analysis would, ideally, be based on an accurate assessment of both the number of cases of illness and the distribution of illness severities associated with those cases. Information on severity characteristics is often limited in the WBDOSS reports because certain kinds of requested information that would be useful for burden estimation are not consistently provided (e.g., duration of illness) or are not even requested on CDC 52.12 (e.g., physician visits). In addition, not all associated cases are recognized or reported (Blackburn et al., 2004). Chapter 2 and Appendix A detail the limitations of the current information in the WBDOSS database. Despite these limitations, the data collected by the WBDOSS constitute the most comprehensive source of information on U.S. outbreaks, and provide a useful basis for demonstrating this surveillance data based approach for developing a burden of disease estimate.

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[5] The current form can be downloaded from www.cdc.gov/healthyswimming/downloads/cdc_5212_waterborne.pdf.

1.3. MEASURES OF THE BURDEN OF DISEASE

While traditional public health measures, such as age-standardized death rates, provide a sense of the relative health of one group of people compared to another, in many cases they are inadequate for the public health decision-making needs of contemporary communities and governments (CDC, 2005; Gold et al., 1996; Murray and Lopez, 1996). Advances in public health and sanitation have brought about such great increases in life expectancy that new methods to evaluate public health consider the quality of life as well as the length of life. Quality-of-life issues, from a public health perspective, include the severity and duration of the illness, injury, or disability; pain and suffering; and the physical, psychological and social impacts of poor health.

While a variety of measures, such as Disability Adjusted Life Years (DALYs),[6] have been employed to estimate disease burden in other studies (Murray and Lopez, 1996; Havelaar et al., 2000; Pruss et al., 2002), we limit the measures used for this analysis to the benefits assessment measures currently employed in U.S. EPA rulemaking procedures (U.S. EPA, 2000a). The U.S. EPA evaluates the monetary burden associated with mortality using the "value of a statistical life" (VSL), which is an approach for determining the economic value of reducing the risk of premature death. The VSL is an aggregate measure of individuals' WTP to avoid a small change in the

[6] DALYs combine information on the burden of premature mortality (in terms of years of life lost) with preferences for quantitative changes in the quality of life associated with morbid conditions. These conditions are evaluated based on severity, which is assigned a quantitative weight, and duration. These weights may be developed through survey techniques. DALYs are the sum of years of life lost and years lived with disability (Murray and Lopez, 1996). Years lived with disability is measured as the product of the duration of the disease and a disability weight. DALYs were developed as a systematic method for estimating morbidity and mortality impacts across different countries and regions of the world (Murray and Lopez, 1996). DALYs are used in cost-effectiveness analyses, which describe the decrease in DALYs per dollar allocated for risk reduction.

risk of dying (Hammitt, 2000; U.S. EPA, 2000a).[7] To estimate the monetary burden associated with the morbidity from waterborne illnesses, U.S. EPA uses COI estimates. For this WBDO analysis, we have employed data derived from several peer-reviewed sources that provide COI estimates specifically for waterborne outbreaks (e.g., Corso et al., 2003; Harrington et al., 1991).

1.4. WILLINGNESS-TO-PAY AND THE VALUE OF A STATISTICAL LIFE

Standard U.S. EPA practice for economic analyses to support environmental decision-making is based on the principles of welfare economics[8] (U.S. EPA, 2000a). WTP measures, which reflect the monetary value that individuals place on benefits that might be achieved by implementation of an action or program, are consistent with those principles (Freeman, 1993). In the public health realm this could include the WTP for a technology or intervention that reduces the risk of contracting future illnesses. WTP frequently functions as an *ex ante*[9] measure because the value of reducing the risk of contracting an illness is, in many cases, decided *before* the risk is incurred. WTP would measure the trade-off between health risk and wealth based on an individual's preferences (Freeman, 1993; Hammitt, 2002). WTP can include valuation of medical and non-medical costs (e.g., expenditures for preventative measures, travel time), lost wages due to the disease, pain and suffering, and premature death (U.S. EPA, 1999, 2000a, 2002).

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[7] Essentially, the VSL is used to represent the benefit of avoiding one generic individual's premature death (rather than that of an identified individual) (see Hammitt [2002] for a theoretical discussion).

[8] "Welfare economics" refers to a branch of economic theory that holds that individuals (rather than elected or appointed decision makers) are the best judges of their own welfare. The basis of welfare economics lies in the premise that social welfare should be comprised of individuals' welfare and that these individuals collectively provide the best information on social welfare issues. It is assumed that resource allocation is appropriately driven by competitive market forces and that income distribution amongst individuals is appropriate.

[9] *Ex ante*, literally translates from Latin as "beforehand." In economic models the *ex ante* values (e.g., of expected gain) are those that are calculated before there is certainty of the outcome.

WTP can be estimated by analyzing revealed preferences from primary "observable" data[10] or through surveys of individuals' stated preferences.[11] The use of either approach can be controversial due to their inherent limitations. For example, the survey approach is criticized because what people say they would do in a hypothetical situation may be quite different from what they would actually do in a real-life situation (Mitchell and Carson, 1989; U.S. EPA, 2000a). VSL – a WTP measure that is specifically concerned with avoiding the risk of death – can be estimated using revealed preference methods or stated preference methods. For example, VSL could be estimated using labor market data and analyzing differences in wages and risks of workplace mortality or asking individuals if they would be willing to pay some specified amount of money to reduce the risk of a premature death by a specified probability. Among the limitations of the VSL approach is uncertainty about the extent to which survey subjects adequately understand the risk of death from the illness under investigation (e.g., see NOAA, 1993; Viscusi, 1993; Viscusi and Aldy, 2003).

An alternative to collecting primary data via observation or survey is to utilize benefit transfer. Benefit transfer applies WTP information from one study to another location or context (Desvousges et al., 1992). The accuracy of benefit transfer depends on the existence and quality of applicable studies. The advantages of benefit transfer includes saving the time and cost of developing new studies. The U.S. EPA typically

[10] For example, to estimate the WTP to avoid giardiasis during an outbreak, Harrington et al. (1989) examined the costs of hauling safe water, boiling water, purchasing bottled water, and expenditures on water filters and purifiers, sometimes referred to as averting behavior.

[11] To determine the benefits of controlling freshwater pollution, Mitchell and Carson (1989) asked American households to value water quality improvements for the U.S.; Viscusi and Aldy (2003) summarized the results of a group of studies in which people were asked if they would pay a certain dollar amount to avoid a specified increased risk of premature death.

transfers VSL estimates related to the number of statistical lives saved by a particular program.

In contrast, information regarding the WTP to avoid gastrointestinal disease morbidity is not readily available for benefit transfer (e.g., see Harrington et al., 1989). Generally speaking, WTP is a more comprehensive measure of total value for avoiding a waterborne illness.[12] However, estimates based on the COI approach will be substituted as an approximation for the WTP to avoid morbidity in accordance with U.S. EPA practice when few WTP studies exist.

1.5. COST-OF-ILLNESS APPROACH

The COI is a human capital approach (i.e., quantifiable in terms of market-place productivity) that is based on measured *ex post* (i.e., known and certain) costs associated with disease (U.S. EPA, 1999, 2000a, 2002; see discussion in Drummond et al., 2000). In this approach, costs are divided into direct costs, which include the market value estimates of treatment costs (e.g., the costs of medication, physician visits, emergency room visits, and hospitalization for infectious diseases), and indirect costs (e.g., lost productivity in the workplace and at home due to morbidity). Although premature death can also be considered an indirect cost when evaluated as lost productivity, a COI approach for mortality valuation is not standard U.S. EPA practice. The COI approach for valuing morbidity provides information on the monetary impact of an outbreak but not necessarily on the severity of the impact (Kuchler and Golan, 1999). COI approaches do not completely capture the impact of an outbreak from a societal

[12] U.S. EPA (2000a) states that WTP estimates could underestimate the social costs because they may not capture health care costs paid by insurance companies, hospitals, or employers (e.g., sick leave).

valuation perspective, because they do not measure individual preferences for avoiding pain and suffering, averting costs, anxiety, or risk attitudes (U.S. EPA, 2000a).

1.6. COMPONENTS OF THE WBDO BURDEN ANALYSIS

We begin the burden analysis by presenting the epidemiologic data in Chapter 2. If sufficient information is not available directly from the WBDOSS, then data gaps are addressed in two ways:

1. Much of the information used to supplement the database gaps is obtained from related data within the WBDOSS itself (e.g., information from a different waterborne outbreak caused by the same or a similar etiologic agent).

2. When the information in the database cannot meet that need, information is obtained from the scientific and medical peer-reviewed literature.

Chapter 3 compares WBDO disease burden estimates (in epidemiologic units) across etiologic agents, source water types, deficiencies and other outbreak characteristics. Chapter 4 provides the methods used to develop the monetary burden. In Chapter 5, we compare the monetary measures of disease burden estimates across etiologic agents, source water types, deficiencies and other outbreak characteristics. Chapter 6 presents three separate sensitivity analyses; these analyses highlight the potential impacts of some of the uncertainties on the monetary burden. The results, conclusions and research needs are discussed in Chapter 7. Appendix A describes the surveillance system and Appendix B categorizes the WBDOs by outbreak investigation method. The annual waterborne outbreak disease burden between 1971 and 2000 is summarized in Appendix C.

2. MEASURES AND METHODS FOR ESTIMATING THE EPIDEMIOLOGIC BURDEN OF INFECTIOUS DISEASE OUTBREAKS ASSOCIATED WITH DRINKING WATER

The epidemiologic burden of the infectious disease outbreaks that were reported to the WBDOSS during the 30-year period from 1971-2000 was evaluated by the following measures of outbreak severity:[1]

- Cases of illness
- Duration of illness (used to compute person-days of illness, i.e., duration of illness × number of cases)
- Physician visits
- Emergency room visits
- Hospitalizations
- Deaths

The measures listed above were not fully reported in the WBDOSS for all of the 665 outbreaks on record. Four of the measures are specifically requested on the standard waterborne diseases outbreak reporting form available from the CDC (CDC 52.12); these include number of persons ill (both actual and estimated), duration of illness (shortest, longest, and median), number hospitalized, and number of fatalities. Although these four types of information were requested, they were not consistently provided. Number of cases (i.e., persons ill) and number of deaths were available for all 665 outbreaks, hospitalization information was included in all but six of the reports and duration of illness was provided for 282 of the outbreaks (Table 2-1). For most of the outbreaks the entries for hospitalizations and deaths were “zero.” The number of

[1] Here “severity measure” is a generic term that describes how severe the outbreak was in terms of how many people were affected, how long their illnesses lasted, what medical services they required, and whether or not the outbreak lead to any deaths.

TABLE 2-1

Availability of Selected Severity Measures in the WBDO Surveillance System (Number of Infectious or Suspected Infectious Drinking Water Outbreaks = 665)

Severity Measure	WBDOs for Which Severity Measure was Reported			Does CDC 52.12 Request this Measure?
	Number	Percent	Reports with Entry of “Zero”	
Cases of Illness	665	100	none	Yes
Duration of illness	282	42	none	Yes
Hospital admissions	659	99	469	Yes
Physician visits	29	4	NA	No
Emergency room visits	15	2	NA	No
Deaths	665	100	559	Yes

NA = not applicable because number was not requested on CDC 52.12

physician visits or emergency room visits was available only when local outbreak investigators provided that information in supplemental reports. Twenty-nine (29) reports included physician visit data and 15 included emergency room visit data.

In this chapter, the epidemiologic burden components are summarized according to the pathogen identified as the etiologic agent of the outbreak. CDC 52.12 requests laboratory findings for patient specimens (e.g., stool), and, consequently, 300 of the 665 outbreaks were attributed to specific waterborne pathogens identified by laboratory analysis. The other 365 outbreaks were identified as “acute gastrointestinal illness of unknown etiology” (AGI) either because laboratory results were not reported or an etiologic agent could not be identified by the tests performed.

When data for a severity measure were missing from a WBDO report, a value was estimated for the burden analysis. These estimated values were based on information extracted from the reports of other WBDOs of similar etiology, or, if WBDOSS data were inadequate, from published sources such as CDC fact sheets.

2.1. CASES OF ILLNESS

The CDC 52.12 form requests information about the number of actual and estimated cases. In the majority of WBDOs (70%), cases of illness were reported as an actual count rather than an estimate. The case numbers presented in this burden analysis are the numbers reported in the WBDOSS regardless of whether the case numbers were actually counted or estimated by local investigators. The number of reported outbreaks attributed to each particular etiologic agent or classed as “AGI” and the total number of reported cases in each category are provided in the second and third columns of Table 2-2.

TABLE 2-2

Durations of Illness (in Days) by Etiologic Agent, WBDOs, 1971 to 2000

Etiologic Agent	All WBDOSS Outbreaks		Outbreaks with Reported Median Durations of Illness (in days)					Estimated Durations for WBDOs without WBDOSS Duration Records	
	Out-breaks	Cases	Out-breaks	Cases	Min-Max	Median of Reported Median Durations	Mean of Reported Median Durations (95% CI)	Mean, Median, or Midpoint (range)	Source
AGI	365	83,493	189	56,401	0.1-60	2	4.2 (3.7-4.9)	4.2	AGI mean from WBDOSS
Viruses									
Norovirus	26	13,100	16	5,870	1-4	1.75	2.0 (1.1-3.2)	2.0	Norovirus mean, WBDOSS
SRSV (assumed to be norovirus)	1	70	1	70	2.0-2.0	2.0	–	2.0	Norovirus mean, WBDOSS
Rotavirus	1	1,761	0	0	–	–	–	5.5 (3-8)	CDC fact sheet[a]
Hepatitis A	28	827	2	45	26-60	43	43.0 (5.2-155.2)	21	Ciocca (2000)

TABLE 2-2 cont.

Etiologic Agent	All WBDOSS Outbreaks		Outbreaks with Reported Median Durations of Illness (in days)					Estimated Durations for WBDOs without WBDOSS Duration Records	
	Out-breaks	Cases	Out-breaks	Cases	Min-Max	Median of Reported Median Durations	Mean of Reported Median Durations (95% CI)	Mean, Median, or Midpoint (range)	Source
Bacteria									
Campylobacter jejuni	19	5,604	8	4,285	2-6	4.8	4.4 (1.9-8.6)	4.4	*C. jejuni* mean, WBDOSS
Escherichia coli	12	1,529	7	1,310	3-9.3	4.3	5.3 (2.1-11.0)	5.3	*E. coli* mean, WBDOSS
E. coli & Campylobacter	1	781	0	0	–	–	–	4.8	Bacterial mean, WBDOSS
Plesiomonas shigelloides	1	60	0	0	–	–	–	4.8	Bacterial mean, WBDOSS
Salmonella, non-typhoid spp.	15	3,203	5	949	2-5	4	3.9 (1.3-9.0)	6 (4-7)	CDC fact sheet[b]
Salmonella enterica serovar Typhi	5	282	1	60	14-14	14	14.0 (0.4-78.0)	21	CDC fact sheet[c]
Shigella	44	9,196	11	4,246	1.5-7	3.3	3.8 (1.9-6.7)	3.8	*Shigella* mean, WBDOSS
Vibrio cholerae	2	28	0	0	–	–	–	4.8	Bacterial mean, WBDOSS
Yersinia	2	103	2	103	5-10	7.5	7.5 (0.9-27.1)	7.5	*Yersinia* mean, WBDOSS

TABLE 2-2 cont.

Etiologic Agent	All WBDOSS Outbreaks		Outbreaks with Reported Median Durations of Illness (in days)					Estimated Durations for WBDOs without WBDOSS Duration Records	
	Out-breaks	Cases	Out-breaks	Cases	Min-Max	Median of Reported Median Durations	Mean of Reported Median Durations (95% CI)	Mean, Median, or Midpoint (range)	Source
Protozoa									
Cryptosporidium	15	421,473	12	408,312	3-74	8.8	18.6 (9.6-32.5)	8.8	*Cryptopsoridium* median, WBDOSS
Cyclospora	1	21	0	0	–	–	–	10 (few-30)	Herwaldt (2000)
Entamoeba histolytica	1	4	0	0	–	–	–	15 (several weeks)	Stanley (2003)
Giardia	126	28,427	28	13,191	0.6-41	12	12.7 (8.4-18.4)	12.7	*Giardia* mean, WBDOSS
Total	665	569,962	282	494,842					

[a] http://www.cdc.gov/ncidod/dvrd/revb/gastro/rotavirus.htm
[b] http://www.cdc.gov/ncidod/dbmd/diseaseinfo/salmonellosis_g.htm
[c] http://www.cdc.gov/ncidod/dbmd/diseaseinfo/typhoidfever_t.htm
SRSV = Small round structured virus

The actual case counts included illnesses reported to the local public health agency or to the local WBDO investigators by physicians, ill persons or clinical laboratories. When local outbreak investigators reported an estimated number of cases, they might have used one of several standard epidemiologic methods to determine the estimate including surveys of selected cohorts, geographic areas, or physicians. The Mac Kenzie et al. (1994) investigation of the Milwaukee *Cryptosporidium* outbreak that occurred in 1993 provides an example of estimation of case numbers. For this investigation, an extensive search was made to identify symptoms, cases, physician visits, and hospitalizations. Investigators identified 285 laboratory-confirmed cases of cryptosporidiosis, and 93% of those cases experienced diarrhea that they characterized as "watery." Another 235 cases of diarrhea experienced during the outbreak time frame (March 1-April 28, 1993) were identified through a telephone survey conducted to identify the clinical symptoms of cryptosporidiosis. Two hundred one (201) of the respondents (86%) reported watery diarrhea symptoms. Subsequently "watery diarrhea" was the case definition used for further case incidence estimation. The number of additional cases attributable to the outbreak was then estimated by means of a second telephone survey of 613 households throughout the greater Milwaukee area. Investigators found that 493 (26%) of the 1663 household members surveyed reported experiencing watery diarrhea at some point during the outbreak time frame. By applying the proportion of survey respondents experiencing watery diarrhea (26%) to the total population at risk (1.61 million people), investigators estimated that 419,000 persons may have been ill with diarrhea during the Milwaukee WBDO. Subtracting a background rate of 0.5% per month (16,000 people) for diarrhea due to causes other than cryptosporidiosis, an estimated 403,000 people had watery diarrhea that could be attributed to the *Cryptosporidium* outbreak.

2.2. DURATION OF ILLNESS

Duration of illness is a valuable outbreak severity characteristic because, by multiplying the typical duration of a particular illness by the number of persons who experienced that illness, we compute the composite burden measure “person-days ill.” The “person-days ill” metric provides a succinct way to compare the population-level health impact of the incidence of different diseases. For example, the public health impact of a norovirus (2-day typical duration of illness) outbreak of 50 cases could be compared to the public health impact of a *Giardia* (12-day typical duration of illness) outbreak of eight cases: 100 person-days ill for the norovirus outbreak, 96 person-days ill for the *Giardia* outbreak. The person-days ill measure will be an important component of the burden summaries in Chapter 3.

A duration-of-illness characteristic of the outbreak was reported for 282 of the 665 WBDOs in the database. We developed estimates for durations of illness for the 383 outbreaks in which these data were missing from the reports. Table 2-2 provides reported and estimated duration-of-illness values. The mean of median durations of illness reported for other WBDOs of the same or similar etiology was the primary source of information for missing values. For example, median duration of illness was reported for 28 of the 126 *Giardia* WBDOs in the database. The mean of these 28 values (12.7 days) was used as an estimate for the other 98 *Giardia* WBDO reports that did not include an entry for duration of illness. The mean of the various median durations of illness for WBDOs attributed to a particular etiologic agent was usually used for the missing data. For most etiologic agents, the overall mean of median durations of illness and the overall median of median durations of illness of were similar. However, for *Cryptosporidium* WBDOs, the mean of the characteristic durations of illness reported for 11 of the outbreaks was considerably greater than the median due to extremely long durations of illness reported for two of them (i.e., 60 days and 74 days). The median of the 11 outbreak durations of cryptosporidiosis (8.8 days) was used for the burden analysis because this more closely corresponds to the duration of 1-2 weeks reported in the CDC fact sheet for cryptosporidiosis (http://www.dpd.cdc.gov/dpdx/HTML/Cryptosporidiosis.htm).

For some of the etiologic agents, there were very few outbreaks with reported durations of illness in the WBDOSS. Our threshold number for estimating missing durations of illness from the WBDO database itself was six or more outbreaks with this information provided. If fewer than six outbreaks were reported for a particular agent, other data sources, or the mean of WBDOSS agent groups, were used to estimate the missing values. Hepatitis A, non-typhoid *Salmonella* spp., *Salmonella enterica* serovar Typhi, *Entamoeba histolytica, Cyclospora*, and rotavirus durations of illness are based on other literature sources (see Table 2-2 footnotes). The estimate for the two *Vibrio cholerae* outbreaks was derived from the mean of median durations of illness of all bacterial WBDOs (rather than other literature). The illnesses that occurred during the two cholera WBDOs were relatively mild, whereas the typical literature values that are available describe severe cases associated with foreign travel. We considered these inappropriate for the domestic outbreaks in the WBDOSS. No duration of illness was reported for the single *Cyclospora* WBDO reported in the surveillance system. We used a duration of illness of 10 days, as reported by Herwaldt and Ackers (1997) for an outbreak in the United States that was associated with imported raspberries. Other data sources were not available for estimating the *Plesiomonas shigelloides* outbreak so the mean of median durations of all bacterial illnesses from the WBDO database was used for this agent.

The Milwaukee outbreak contributes a considerable portion of the total number of person-days ill to this WBDO burden analysis (see Chapter 3). While the large estimated case number (403,000) is one aspect of the person-days ill burden, the magnitude of this component is also influenced by the duration-of-illness value recorded in the WBDOSS (i.e., 9 days). Although Mac Kenzie et al. (1994) report a single duration value of 9 days in the abstract of their published article, their outbreak investigation involved three different surveys of persons in the Milwaukee area during the outbreak. Each group was characterized by different mean and median illness durations: (1) persons with laboratory confirmed cryptosporidiosis (median, 9 days), (2) persons with clinical symptoms consistent with cryptosporidiosis) (median, 3 days), and (3) a household survey of persons with watery diarrhea (median, 3 days) (Table 2-3). The reported duration of illness among these populations ranged from 1 to 55 days. Of the 285 laboratory-confirmed cases, 46% were hospitalized and 48% were immuno-compromised, and these cases may have been among the most severe. A 3-day duration measure in contrast to the 9-day duration measure greatly affects the person-days ill component of the Milwaukee outbreak; this effect will be described in Chapter 3.

TABLE 2-3

Duration of Illness, Milwaukee *Cryptosporidium* Outbreak (Mac Kenzie et al., 1994)

Population Surveyed	Duration (Days)			Survey Information
	Median	Mean	Range	
Laboratory-Confirmed Cases	9	12	1-55	n = 285 lab confirmed cases
Clinical Infection	3	4.5	1-38	n = 201 respondents with watery diarrhea (482 total respondents)
Household Survey	3	-	1-45	n = 436 interviewees reporting watery diarrhea (out of 1663 total household members)

2.3. PHYSICIAN VISITS

The number of physician visits is assumed to be underreported in the WBDOSS because this information is not requested on CDC 52.12. Among the 29 WBDO reports that included supplementary physician visit data, only 5.2% of all cases reported for those 29 WBDOs were associated with such visits. When available, we used the physician visit rate reported in the WBDOSS for the same etiologic agent to estimate unreported rates (Table 2-4). For example, for the 118 WBDOs of giardiasis for which no physician visits were reported, we estimated a physician-visit ratio of 307.4 physician visits per 1,000 reported cases based on the physician visit reports provided with 8 of the126 total giardiasis WBDOs. If no WBDO reports for a particular agent included physician visit information, we pooled information from the relevant class of agent as an estimate. For example, the physician visit counts for the one *Cryptosporidium* and the eight *Giardia* outbreak reports that included that information were pooled and the sum was divided by the total cases reported for those nine outbreaks to compute a physician visit ratio estimate of 50.6/1000 to apply to the other protozoan outbreaks (*Cyclospora* and *En. histolytica*).

Information for physician visit rates was extremely limited for the bacterial and viral agents. For bacterial outbreaks, there were data for two *C. jejuni* WBDOs (51 physician visits out of 880 reported cases) and for one *S. enterica* serovar Typhi outbreak (for which there were only two cases reported, and both cases involved a physician visit). Because the reported typhoid outbreak was so small and because typhoid tends to be a markedly more severe illness than the other bacterial illnesses reported to the WBDOSS, we elected to use only the physician visit rate for *C. jejuni* as

TABLE 2-4

Physician Visits (PV) by Etiologic Agent, Reported WBDOs, 1971 to 2000

Etiologic Agent	All WBDOSS Outbreaks		WBDOs that Reported Physician Visits				Estimated (PV/1000 Cases)	Source of PV Value (all from WBDOSS data)
	Out-breaks	Cases	Out-breaks	Cases	PVs Reported in WBDOSS	PV per 1000 Cases		
AGI	365	83,493	14	7,664	810	105.7	105.7	AGI
Viruses								
Norovirus	26	13,100	-	-	-	-	82.9	Rotavirus
SRSV (assumed to be norovirus)	1	70	-	-	-	-	82.9	Rotavirus
Rotavirus	1	1,761	1	1,761	146	82.9	82.9	Rotavirus
Hepatitis A	28	827	2	103	100	970.9	970.9	Hepatitis A
Bacteria								
C. jejuni	19	5,604	2	880	51	58.0	58.0	*C. jejuni*
E. coli	12	1,529	-	-	-	-	58.0	*C. jejuni*
E. coli & Campylobacter	1	781	-	-	-	-	58.0	*C. jejuni*
P. shigelloides	1	60	-	-	-	-	58.0	*C. jejuni*

TABLE 2-4 cont.								
Etiologic Agent	All WBDOSS Outbreaks		WBDOs that Reported Physician Visits				Estimated (PV/1000 Cases)	Source of PV Value (all from WBDOSS data)
	Out-breaks	Cases	Out-breaks	Cases	PVs Reported in WBDOSS	PV per 1,000 Cases		
Salmonella, non-typhoid spp.	15	3,203	-				58.0	*C. jejuni*
S. enterica serovar Typhi	5	282	1	2	2	1,000	1,000	*S. enterica* serovar Typhi
Shigella	44	9,196	-	-	-	-	58.0	*C. jejuni*
V. cholerae	2	28	-	-	-	-	58.0	*C. jejuni*
Yersinia	2	103	-	-	-	-	58.0	*C. jejuni*
Protozoa								
Cryptosporidium	15	421,473	1	403,000	20,280	50.3	50.3	*Cryptosporidium*
Cyclospora	1	21	-	-	-	-	50.6	All protozoa
En. histolytica	1	4	-	-	-	-	50.6	All protozoa
Giardia	126	28,427	8	462	142	307.4	307.4	*Giardia*
Total	665	569,962	29	413,872	21,531			

the representative bacterial WBDO physician visit rate (58/1000). For viral outbreaks of gastroenteritis, physician visits were reported for only one WBDO Hepatitis A is not included in this group.[2] The physician visit rate derived from the one rotavirus WBDO serves as the estimated rate for norovirus and SRSV.

We estimated physician visits only for those WBDOs in which the number of hospitalizations constituted fewer than 75% of the reported cases of illness (n = 629). If the number of hospitalizations was greater than 75%, we assumed the severity of the outbreak illnesses resulted in few cases treated on an outpatient basis.

Because the physician visit estimates are based upon very few reported values (recall that this information is not requested on CDC 52.12), and we were unable to locate peer-reviewed literature for alternative estimates, this component of the burden estimate is highly uncertain. The sensitivity of the burden estimate to the uncertainty of the physician visit data is explored in Chapter 6.

2.4. EMERGENCY ROOM VISITS

As with physician visits, the reporting of emergency room visits during a WBDO is not requested on CDC 52.12. Supplementary information provided with some reports identified only 6% of cases identified in those reports as being associated with emergency room visits. Supplementary information on emergency room visits was provided with a few reports (15) and in these outbreaks only 6% of cases were associated with emergency room visits.

[2] Unlike the other viral agents in the WBDO database (i.e., rotavirus, norovirus, and SRSV), Hepatitis A causes non-gastrointestinal illness. Hepatitis tends to be considerably more severe than the GI illnesses caused by the other viruses, so we have elected to present Hepatitis A WBDO data separately from other viral WBDOs and restrict the physician visit estimate for non-reported norovirus to data from a GI viral WBDO.

Since emergency room visits were infrequently reported, most estimates were based on the pathogen group. For example, emergency room visits were reported for only one of the 126 giardiasis outbreaks and none of the other protozoan outbreaks; the rate for that one outbreak (29.1 per 1,000 reported cases) is used for all protozoan WBDOs. The values used to estimate the burden are shown in Table 2-5. Similar to unreported physician visits, unreported emergency room visits were estimated only for WBDOs in which less than 75% of cases were hospitalized.

Since the number of WBDOs resulting in reported emergency room visits was small, there is considerable uncertainty in this outbreak severity measure category. To our knowledge, there are no other sources in the peer-reviewed literature that can be used for alternative estimates. The sensitivity of the burden estimates to the uncertainty of the data on emergency room visits is explored in Chapter 6.

2.5. HOSPITALIZATIONS

The surveillance report form (CDC 52.12) requests the number of hospitalizations occurring during an outbreak, and 659 of the WBDO reports (99%) included this information. An entry of “zero” was provided in 496 of the reports; one or more hospitalizations were recorded in each of the remaining 163 reports, for a total of 5915 hospitalizations. Because this information was reported for almost all of the WBDOs, the hospitalization rates for WBDO illnesses were determined by dividing the number of reported hospitalizations for an etiologic agent by the total number of cases reported for that agent (Table 2-6). Because the reporting frequency was 99%, no additional hospitalizations were estimated.

TABLE 2-5

Emergency Room (ER) Visits by Etiologic Agent, WBDOs, 1971 to 2000

Etiologic Agent	All WBDOSS Outbreaks		WBDOs that Reported Emergency Room Visits				Estimated (ER/1,000 Cases)	Source (all from WBDOSS Data)
	Outbreaks	Cases	Outbreaks	Cases	ER Visits in WBDOSS	ER Visits/ 1,000 Cases		
AGI	365	83,493	9	7,839	885	112.9	112.9	AGI
Viruses								
Norovirus	26	13,100	1	1,500	5	3.3	3.3	Norovirus
SRSV (assumed to be norovirus)	1	70	0	0	0	0	3.3	Norovirus
Rotavirus	1	1,761	0	0	0	0	3.3	Norovirus
Hepatitis A	28	827	1	22	2	90.9	90.9	Hepatitis A
Bacteria								
C. jejuni	19	5,604	2	3,871	11	2.8	2.8	*C. jejuni*
E. coli	12	1,529	0	0	0	0	4.8[a]	All bacteria*
E. coli & Campylobacter	1	781	0	0	0	0	4.8	All bacteria
P. shigelloides	1	60	0	0	0	0	4.8	All bacteria
Salmonella, non-typhoid spp.	15	3,203	0	0	0	0	4.8	All bacteria

TABLE 2-5 cont.									
Etiologic Agent	All WBDOSS Outbreaks		WBDOs that Reported Emergency Room Visits				Estimated (ER/1,000 Cases)	Source (all from WBDOSS Data)
	Outbreaks	Cases	Outbreaks	Cases	ER Visits in WBDOSS	ER Visits/ 1,000 Cases		
S. enterica serovar Typhi	5	282	0	0	0	0	4.8	All bacteria
Shigella	44	9,196	1	83	8	96.4	96.4	Shigella
V. cholerae	2	28	0	0	0	0	4.8	All bacteria
Yersinia	2	103	0	0	0	0	4.8	All bacteria
Protozoa								
Cryptosporidium	15	421,473	0	0	0	0	29.1	*Giardia*
Cyclospora	1	21	0	0	0	0	29.1	*Giardia*
En. histolytica	1	4	0	0	0	0	29.1	*Giardia*
Giardia	126	28,427	1	3,500	102	29.1	29.1	*Giardia*
Total	665	569,962	15	16,815	1,013			

* A total of 19 ER visits were reported for the three outbreaks attributed to bacteria that included supplemental ER information (11 for *C.jejuni* + 8 for *Shigella*). The total case number of these three outbreaks was 3954. The "all bacteria" ER hospitalization rate was computed as: (3,954 / 19) * 1000.

TABLE 2-6

Hospitalizations, Reported WBDOs, 1971 to 2000

Etiologic Agent	All WBDOs Outbreaks		WBDOs with Reported Hospitalizations			Hospitalization Rate (Hospitalized cases/1,000 total cases)
	Outbreaks	Cases	Outbreaks	Cases	Hospitalizations	
AGI	365	83,493	61	41,710	378	4.5
Viruses						
Norovirus	26	13,100	4	1,154	10	0.8
SRSV (assumed to be norovirus)	1	70	0	–	–	0
Rotavirus	1	1,761	0	–	–	0
Hepatitis A	28	827	12	348	82	99.1
Bacteria						
C. jejuni	19	5,604	8	5,178	87	15.5
E. coli	12	1,529	9	520	122	79.8
E. coli & Campylobacter	1	781	1	781	71	90.9
P. shigelloides	1	60	1	60	3	50
Salmonella, non-typhoid spp.	15	3,203	8	1,910	82	25.6
S. enterica serovar Typhi	5	282	4	277	238	844
Shigella	44	9,196	22	5,813	301	32.7

TABLE 2-6 cont.

Etiologic Agent	All WBDOs Outbreaks		WBDOs with Reported Hospitalizations			Hospitalization Rate (Hospitalized cases/1,000 total cases)
	Outbreaks	Cases	Outbreaks	Cases	Hospitalizations	
V. cholerae	2	28	1	11	4	142.9
Yersinia	2	103	2	103	20	194.2
Protozoa						
Cryptosporidium	15	421,473	7	407,521	4,448	10.6
Cyclospora	1	21	0	–	–	0
En. histolytica	1	4	1	4	1	250.0
Giardia	126	28,427	22	13,423	68	2.4
Total	665	569,962	163	478,813	5,915	

Although we did not employ any estimation procedures to supplement the hospitalization data from the WBDOSS, in Section 2.6.1 we offer the interested reader a comparison of the WBDO rates of hospitalization to those estimated by Mead et al. (1999). The Mead et al. study was designed to evaluate the impact of foodborne illnesses on the disease burden in the U.S. due to infectious agents that primarily cause gastrointestinal illnesses.

2.6. MORTALITY

CDC 52.12 requests the number of fatalities associated with a WBDO, and all WBDO reports included an entry for deaths. For the vast majority, this entry was "zero," but for six of the WBDOs one or more deaths were reported (Table 2-7). Because this information was reported for all of the WBDOs, the fatality-case ratios for WBDO illnesses were determined by dividing the number of reported deaths for an etiologic agent by the total number of cases from all outbreaks reported for that agent and normalizing these ratios to 100,000 cases.

It is unclear to what extent local investigators conducted specific analyses of mortality or searched death certificates for possible WBDO-related deaths. For the Milwaukee outbreak, Hoxie et al. (1997) assessed cryptosporidiosis-associated mortality incidence before, during, and after the 1993 WBDO period. They reported that an excess of 50 deaths occurred as a result of the WBDO; the underlying cause of most of these deaths was Acquired Immunodeficiency Syndrome (AIDS) with cryptosporidiosis listed as a contributing cause. However, investigators who reported deaths for other WBDOs did not specify the source of information about the deaths nor

TABLE 2-7

Mortality Reported in the WBDOSS, 1971-2000, by Etiology

Etiologic Agent	Reported Outbreaks		Outbreaks with One or More Reported Deaths			Case Fatality Ratio per 100,000 cases (Reported Deaths divided by Reported Cases x 100,000)
	Outbreaks	Cases	Outbreaks	Cases	Reported Deaths	
AGI	365	83,493	1	38	1	1.2
Viruses						
Norovirus	26	13,100	0	–	–	–
SRSV (assumed to be norovirus)	1	70	0	–	–	–
Rotavirus	1	1,761	0	–	–	–
Hepatitis A	28	827	0	–	–	–
Bacteria						
C. jejuni	19	5,604	0	–	–	–
E. coli	12	1,529	1	243	4	261.6
E. coli & Campylobacter	1	781	1	781	2	256.1
P. shigelloides	1	60	0	–	–	–
Salmonella, non-typhoid spp.	15	3,203	1	625	7	218.5
S. enterica serovar Typhi	5	282	0	–	–	–

TABLE 2-7 cont.						
Etiologic Agent	Reported Outbreaks		Outbreaks with One or More Reported Deaths			Case Fatality Ratio per 100,000 cases (Reported Deaths divided by Reported Cases x 100,000)
	Outbreaks	Cases	Outbreaks	Cases	Reported Deaths	
Shigella	44	9,196	1	94	2	21.7
V. cholerae	2	28	0	–	–	–
Yersinia	2	103	0	–	–	–
Protozoa						
Cryptosporidium	15	421,473	1	403,000	50	11.9
Cyclospora	1	21	0	–	–	–
En. histolytica	1	4	0	–	–	–
Giardia	126	28,427	0	–	–	–
Total	665	569,962	6	404,781	66	

did they note whether the infectious disease of the outbreak was the underlying or a contributing cause of death.

Issues associated with the possible under- or over-reporting of mortality are discussed in Section 2.6.2.

2.6.1. Comparison of WBDOSS and Mead et al. (1999) Hospitalization Rates. To explore possible under- or over-reporting of hospitalizations in the WBDOSS, we compared the pathogen-specific and AGI hospitalization rates for the reported WBDOs with pathogen-specific and AGI hospitalization rates reported in Mead et al. (1999). The objective of the Mead et al. report was to estimate the burden of foodborne infectious disease in the U.S.; the paper, however, also reports estimates of total numbers of cases, hospitalizations, and deaths associated with microbial pathogens that, though potentially foodborne, can also be transmitted by water or person-to-person contact. Mead et al. used information from a number of surveillance sources including the *Foodborne Diseases Active Surveillance Network* (FoodNet) (CDC, 1999a), the *National Notifiable Diseases Surveillance System* (CDC, 1998a), the *Public Health Laboratory Information System* (Bean et al., 1992), the *Gulf Coast States Vibrio Surveillance System* (Levine and Griffin, 1993), the *Foodborne Disease Outbreak Surveillance System* (Bean et al., 1990), the *National Hospital Ambulatory Medical Care Survey* (Woodwell, 1997), the *National Hospital Discharge Survey* (Graves and Gillium, 1997), the *National Vital Statistics System* (McCaig and McLemore, 1994; McCaig, 1997; McCaig and Stussman, 1997), CDC reports, and selected published studies. The Mead et al. report included pathogen-specific hospitalization rates for cases that were culture-confirmed or actually reported (to FoodNet, CDC, published outbreak reports), and estimated numbers of hospitalizations for estimated total case numbers (Table 2-8). We also provide WBDOSS hospitalization rates in Table 2-8 for comparison.

The values for the confirmed/reported cases from Mead et al. (Table 2-8, fourth column) reflect higher hospitalization rates while the rates for estimated total case numbers (Table 2-8, fifth column) are typically lower. Consider that patients hospitalized for gastrointestinal illness would be routinely tested for pathogens; this routine would inherently demonstrate a high hospitalization rate among the cases confirmed by hospital laboratories. In contrast, the estimated-cases category would include many mild and non-medically-attended cases – so a lower hospitalization rate would be expected. The WBDO hospitalization rates generally fall between the confirmed/reported and estimated rates of Mead et al., or near the estimated rate. The exceptions were WBDOs of *Cyclospora*, *V. cholerae*, *S. enterica* serovar Typhi, and rotavirus. For *Cyclospora*, the case number sample size (n=21) in the WBDO database was too small to expect representative information regarding this agent. The *V. cholerae* hospitalization rate from Mead et al. was based almost exclusively on foreign-acquired infection and may not be appropriate for the two WBDOs in the U.S. that were characterized by relatively mild illness for this pathogen. The hospitalization rate for WBDOs of *S. enterica* serovar Typhi is somewhat higher than the Mead et al. rates, but all the presented rates (844, 750, and 750 hospitalizations per 1,000 reported cases) are markedly higher than that for any other pathogen and the relative difference between them is small. There were no reported hospitalizations associated with the single reported WBDO of rotavirus that occurred primarily among adult tourists (n=1761)

TABLE 2-8

Hospitalization Rate (Hospitalized cases per 1,000 cases)

Etiologic Agent	Total WBDO Cases	WBDOSS (Based on reported hospitalizations relative to total WBDO Cases)	Mead et al. (1999) (Appendix); Culture-Confirmed/Reported (Based on reported cases)	Mead et al. (1999); Estimated (Based on estimated total cases)[a]
AGI	83,493	4.5	-	4.5
Viruses				
Norovirus	13,100	0.8	-	2.1
SRSV (assumed to be norovirus)	70	0	-	-
Rotavirus	1,761	0	-	12.8
Hepatitis A	827	99.1	130	130
Bacteria				
C. jejuni	5,604	15.5	102	5.4
E. coli	1,529	79.8	295	29.5
E. coli & Campylobacter	781	90.9	-	-
P. shigelloides	60	50	-	-
Salmonella, non-typhoid spp.	3,203	25.6	221	11.6
S. enterica serovar Typhi	282	844	750	750
Shigella	9,196	32.7	139	13.9
V. cholerae	28	143	340[c]	333[b]
Yersinia	103	194	242	12.7
Protozoa				
Cryptosporidium	421,473	10.6	150	6.6
Cyclospora	21	0	20	1.0
En. histolytica	4	250	-	-
Giardia	28,427	2.4	-	2.5[c]

[a] The estimated rate for hospitalizations amongst total estimated cases was determined by dividing the total estimated hospitalizations by the total estimated illnesses for each pathogen. These case and hospitalization numbers for specific pathogens are provided by Mead et al. (1999) in their Table 3, and for AGI in their Figure 1.

[b] 96% of cases reported to CDC were acquired abroad

[c] Estimated hospitalization rate by Mead et al. (1999)

in a resort area. The hospitalization rate estimated by Mead et al. for rotavirus (12.8/1,000) probably reflects the hospitalization rate for young children who typically experience much more severe illness from rotavirus infections than do adults.

2.6.2. Fatality per Case Estimations. Although all the WBDO reports included entries for deaths due to the outbreak, under- or over-reporting of the number of deaths is possible. Deaths that occur as a result of a WBDO-acquired illness may not get attributed to that incident on the WBDOSS report or on the patient's death certificate. Unless an outbreak investigation includes an evaluation of death certificates or a mortality study that considers deaths before, during, and after the WBDO, reported deaths might not represent the actual mortality attributable to the incident. Even though a death may occur during the outbreak period or shortly thereafter, an attending physician may not certify that the WBDO pathogen was a contributing or underlying cause of death, or an outbreak investigator may not conclude that a death is WBDO-related, even if the illness or infectious agent etiology is listed on the death certificate. For example, no deaths were indicated on the CDC 52.12 filed to report a cryptosporidiosis outbreak that occurred in Clark County, Nevada over the first 3 months of 1994. However, there were at least 20 cryptosporidiosis-associated deaths among HIV-positive persons that occurred in Clark County by the end of June that year (Goldstein, 1996). Although these deaths may have been attributable to the waterborne outbreak, they are not recorded in the WBDOSS.

To investigate possible under- or over-reporting of mortality resulting from WBDOs, we considered four other estimates of mortality due to infectious diseases that can be food or waterborne (Table 2-9). Three of the other compilations address the

TABLE 2-9

Case Fatalities per 100,000 Cases According to WBDOSS and Other Sources

Etiologic Agent	WBDOSS (1971 to 2000)	Foodborne Outbreaks Reported to CDC: 1983-1987; CAST (1994)	Mead et al. (1999)		Bennett et al. (1987) from *Closing the Gap*	Todd (1989) for Foodborne Disease[c]	
			Based on Culture-Confirmed or Reported to FoodNet/CDC	Based on Estimated Cases[a]	Based on "Est. True Annual Incidence" CDC Survey Data[b]	Based on Reported Cases	Based on Estimated Cases
AGI	1.2	-	-	2[d]	-	40	0.4
Viruses							
Norovirus	0	0	-	1[e]	0.1	0.1	0
SRSV (assumed to be norovirus)	-	-	-	-	-	-	-
Rotavirus	0	0	-	0[f]	10	-	-
Hepatitis A	0	94	300[g]	100	300	300	3
Bacteria							
C. jejuni	0	138	100[h]	5.1	100	50	0.5
E. coli O157:H7 and *E. coli* O157:H7 from mixed outbreak	260	625	830[i]	83	200	2,000	20
P. shigelloides	0	-	-	-	-	-	-
Salmonella, non-typhoid spp.	219	125	780[j]	41	100	100	1.1
S. enterica serovar Typhi	0	-	400[k]	364	6,000[l]	-	60
Shigella	21.7	30	160[j]	15.6	200	125	1.25
V. cholerae	0	0	600[m]	0	1,000[l]	1,000	10

TABLE 2-9 cont.							
Etiologic Agent	WBDOSS (1971 to 2000)	Foodborne Outbreaks Reported to CDC: 1983-1987; CAST (1994)	Mead et al. (1999)		Bennett et al. (1987) from *Closing the Gap*	Todd (1989) for Foodborne Disease[c]	
			Based on Culture-Confirmed or Reported to FoodNet/CDC	Based on Estimated Cases[a]	Based on "Est. True Annual Incidence" CDC Survey Data[b]	Based on Reported Cases	Based on Estimated Cases
Yersinia	0	-	50[n]	3.1	50	25	0.25
Protozoa							
Cryptosporidium	11.9	-	500[o]	22	50,000[l]	-	-
Cyclospora	0	-	50[p]	0	-	-	-
En. histolytica	0	-	-	-	300	-	-
Giardia	0	0	-	0.5[q]	0.1	1	0

[a] Table 3, Mead et al. (1999), Estimated total deaths/Estimated total cases.
[b] From chapter entitled "Infectious and Parasitic Diseases" in *Closing the Gap: the Burden of Unnecessary Disease,* a 1987 Carter Center Report. Estimates acquired from CDC experts and based on 1985 case incidence and infection-attributable death records.
[c] Fatality:case ratios (as %) presented in Table 2, Todd (1989). Note: Fatality:case ratios for estimated cases assumed to be 100X lower than for reported cases.
[d] 5,000 deaths/173,000,000 cases AGI (Figure, Mead et al., 1999)
[e] Assumed to account for 11% of 2,800 fatal cases of viral AGI each year. Mead appendix reference to Mounts et al. (1999).
[f] "Very low." Mead appendix reference to Kilgore et al. (1995).
[g] Based on hepatitis surveillance. Mead appendix references to Hepatitis surveillance report no. 56 (1996) and Hoofnagle et al. (1995).
[h] Culture-confirmed cases reported to FoodNet, 1996/97. Mead appendix reference to FoodNet (CDC, 1998b,c).
[i] Mortality associated with sporadic cases reported to FoodNet, 1996/97. Mead appendix reference to FoodNet (CDC, 1998b,c).
[j] Average case-fatality rate reported to FoodNet, 1996/97. Mead appendix reference to FoodNet (CDC, 1998b,c).
[k] Based on outcomes of 2254 cultured-confirmed cases. Mead appendix reference to Mermin et al. (1998).
[l] Based on small numbers: Typhoid 36 deaths/600cases; Cholera 3 deaths/25 cases; Crypto 25 deaths/50 cases.
[m] Based on cases reported to CDC, 1992-94. Mead appendix reference to Mahon et al (1996).
[n] Case-fatality rate assumed to be low (0.5%) based on 1996 FoodNet surveillance. Mead appendix reference to FoodNet (CDC, 1998b).
[o] Average case-fatality rate among cases reported to FoodNet, 1997/98. Mead appendix reference to FoodNet (CDC, 1999).
[p] Case-fatality rate assumed low (0.5%). Mead appendix reference to Herwaldt and Ackers (1997) and Herwald and Beach (1999).
[q] Case-fatality rate assumed to be "exceedingly low" (Mead et al., 1999 [appendix]).

burden of foodborne illnesses: Mead et al. (1999), Todd (1989) and the Council for Agricultural Science and Technology (CAST, 1994) and the fourth, Bennett et al. (1987), addresses the burden of all infectious diseases in the U.S.

Drawing from the information in the resources listed in the hospitalization-rate discussion above, Mead et al. reported pathogen-specific fatality-case ratios for confirmed/reported cases, and estimated the number of deaths occurring amongst the estimated total cases. Todd's fatality-case ratios were based upon the Bennett et al. (1987) report and other sources including CDC annual summary data, CDC correspondence, and published reports. The CAST task force compiled case number and mortality data reported for foodborne outbreaks that occurred in the period from 1983 through 1987. The fatality-case ratios reported by Bennett et al. were obtained from survey data collected from experts in the various divisions of the CDC regarding infectious disease incidence in 1985.

Note that the Mead et al., CAST, and Todd fatality-case ratios for "reported" cases in Table 2-9 are consistently greater than those for "estimated" cases. This phenomenon occurs because estimated case numbers include unreported cases and, frequently, unreported cases include the milder episodes of illness, many of which do not require medical attention. Far fewer fatalities per incident number of cases can be expected when large numbers of mild cases are included in the total. Furthermore, culture-confirmation of a case would much more likely be sought for patients who present to their physicians with severe symptoms; consequently, a higher fatality-case ratio can be expected for culture-confirmed cases. To estimate the number of deaths occurring among the estimated cases, Mead et al. calculated the number of reported pathogen-specific deaths available from FoodNet, reported outbreaks, and other published sources (see footnotes, Table 2-9) and assumed that twice that many deaths might have occurred among the estimated cases (two deaths/estimated total). For those viral and protozoan agents with no reported deaths, the fatality-case ratio was estimated from literature review. Todd assumed that the fatality-case ratio for estimated case incidence was 100-fold less than that computed for reported cases. The approach for determining fatality-case ratios in Bennett et al. is unclear and appears to represent estimated cases for some etiologic agents and reported cases for others. The fatality-case ratios for some of the etiologic agents in the Bennett et al. report appear to be based on very low case numbers, such as those for *Cryptosporidium*, *V. cholerae,* and *S. enterica* serovar Typhi. The reporting of very few cases of cryptosporidiosis by Bennett et al. and the extremely high fatality-case ratio associated with them were likely affected by the fact that these data are from 1985, which was very early in the course of the U.S. HIV-AIDS epidemic. Prior to the AIDS epidemic, cryptosporidiosis was rarely recognized or reported. In 1985 it would likely have been the severe and often fatal cases of cryptosporidiosis that occurred in AIDS patients that were noted and reported.

Fatality-case ratios for the reported WBDOs were zero except for *E. coli* O157:H7 (and one WBDO attributed to *E. coli* O157:H7 and *Campylobacter* but in which the deaths were specifically associated with *E. coli* O157:H7), non-typhoid *Salmonella* spp*., Shigella, Cryptosporidium*, and AGI. Fatality-case ratios of zero can be expected among many of the reported WBDO etiologies, in part, because so few cases of any of the types of infectious diseases included in the WBDOSS are reported, and, in general, overall fatality-case ratios for these diseases are low when the total case incidence from all causes is estimated. For example, using the fatality-case ratio developed by the most recent literature source considered here – Mead et al. (1999) – one death per 20,000 estimated cases of campylobacteriosis could be expected (fatality-case ratio, 0.00005). Since the WBDOSS includes only 5604 cases attributable to *Campylobacter* spp., it is not surprising that there was no report of deaths.

Because case number totals for all etiologic agents reported to the WBDOSS included not only symptom- and culture-confirmed cases, but also, for some outbreaks, estimated case numbers, it is reasonable to expect that for some agents, the fatality-case ratios would be closer to the reported/confirmed case ratios provided by CAST, Mead et al., and Todd, while for others they would be closer to the estimated case ratios, depending on the proportion of estimated cases in the WBDO case total for a particular agent. And, except for *Cryptosporidium*, all WBDO agent categories that included a non-zero fatality-case ratio (AGI, *E. coli* O157:H7, non-typhoid *Salmonella* spp., and *Shigella*) fall between the confirmed/reported and estimated values of the literature based compilations. The WBDOSS fatality-case ratio for *Cryptosporidium* is less than the lowest literature-source value of 22 deaths/100,000 cases proposed by Mead et al. for estimated cases (Table 3, Mead et al., 1999), but at 11.9 deaths/100,000 cases, not markedly so. We considered the range for the number of deaths that might have occurred during the 30-year WBDO reporting period if the fatality-case ratios acquired from the aforementioned literature sources were used for estimation of the expected (rather than WBDOSS-reported) number of deaths. We applied the lowest and the highest values offered by the four sources (except for the Bennett

Cryptosporidium[3] and *S. enterica* serovar Typhi[4] values) to the reported case numbers in the WBDO database to estimate the lowest and highest number of deaths that could plausibly be expected (Table 2-10). All of the lowest values for predicted numbers of deaths from WBDOs are based on fatality-case ratios developed for estimated case totals. Many (9 of 15) of the lowest values are based on the fatality-case ratios provided by Todd for estimated cases (who assumed that the fatality-case ratio for estimated cases is 1/100 of that computed for reported/confirmed cases). All the highest predicted death numbers were calculated from fatality-case ratios that were based on reported/confirmed cases, and these are all greater than the reported WBDO number of deaths.

For three of the pathogen classifications, AGI, *E. coli* O157:H7, and *Cryptosporidium,* the high estimates were markedly greater than the reported WBDO deaths. Todd selected a 40/100,000 fatality-case ratio for 6309 reported cases of AGI and cites CDC annual summary data as his source (CDC, 1981a,b, 1983a,b; MacDonald and Griffin, 1986). Todd also provided the highest *E. coli* O157:H7 fatality-case ratio (2000 deaths/100,000 reported cases) for 30 reported cases as ascertained from the same CDC annual summaries cited above. The highest fatality-case ratio for cryptosporidiosis was provided by Bennett et al.; however, their 50,000 deaths/100,000 cases value indicates that there would have been over 200,000 deaths due to the

[3] The Bennett et al., 50% fatality ratio is unrealistically large having been based on only the 50 cases that were estimated to be the "current incidence" in 1987 as determined by CDC experts from data collected in 1985. Furthermore, these may have been particularly severe considering that effective antiretroviral therapy for AIDS patients was not generally available at that time.

[4] The Bennett et al., fatality-case ratio for typhoid was based on the expectation of 36 deaths among 600 cases (6% of cases). This appears to be an exceptionally high value considering that Mermin et al. (1998), of the Foodborne and Diarrheal Diseases Branch of the CDC examined 2445 reports of culture-confirmed typhoid received by the CDC between 1985 and 1994 and found only 10 deaths reported from these cases (0.4%).

TABLE 2-10

Comparison of Number of Deaths Reported in WBDOs with Expected Number of Deaths Using Literature-based Fatality-case Ratios
(Rounded to nearest whole number; if values are < 0.5 but > 0, the entry is "< 1")

	WBDO Reported Deaths	Low Estimate from Literature Sources	High Estimate from Literature Sources
AGI	1	<1[a]	33[b]
Viruses			
Norovirus	0	<1[b]	<1[c]
SRSV (assumed to be norovirus)	0	–	–
Rotavirus	0	<1[c]	<1[d]
Hepatitis A	0	<1[a]	2[e]
Bacteria			
C. jejuni	0	<1[a]	8[f]
E. coli O157:H7 and mixed *E. coli* O157:H7[g] *& C. jejuni*	6	<1[a]	46[b]
P. shigelloides	0	–	–
Salmonella, non-typhoid spp.	7	<1[a]	25[e]
S. enterica serovar Typhi	0	<1[a]	1[e]
Shigella	2	<1[a]	18[d]
V. cholerae	0	0[c]	<1[d]
Yersinia	0	0[a]	<1[e]
Protozoa			
Cryptosporidium	50	93[c]	2,107[e]
Cyclospora	0	0[c]	<1[e]
En. histolytica	0	–	<1[d]
Giardia	0	0[a]	<1[b]
Totals	66	94	2,243

[a] Based on Todd, fatality-case ratio for estimated case numbers.
[b] Based on Todd, fatality-case ratio for confirmed/reported case numbers.
[c] Based on Mead et al., fatality-case ratio for estimated case numbers.
[d] Based on Bennett et al., fatality-case ratios.
[e] Based on Mead et al., fatality-case ratio for confirmed/reported case numbers. See Footnotes 3 and 4 in text regarding Bennett et al.'s higher estimates for *S. enterica* serovar Typhi and *Cryptosporidium.*
[f] based on CAST, fatality-case ratios
[g] deaths and majority of infections in this outbreak due to *E. coli* O157:H7

Milwaukee outbreak. Because that estimation is implausibly excessive, we used the fatality-case ratio acquired from Mead et al. (based on 450 cases of cryptosporidiosis reported to FoodNet in 1997-1998) for our upper-end estimate of *Cryptosporidium*-associated WBDO deaths in Table 2-10.

Over the 30-year surveillance period, 66 deaths were reported to the WBDOSS. If the lowest and highest literature-based fatality-case ratios are used, without modification, to predict the number of expected deaths among the cases in the WBDOSS, the range would be 94-2243 (Table 2-10). Obviously, these values are driven by the cryptosporidiosis case incidence due to the Milwaukee outbreak. Because the Milwaukee case incidence was estimated (only 285 cases were culture-confirmed) we contend that the Mead et al. fatality-case ratio based on estimated cases (22/100,000) is the more appropriate choice for establishing a plausible range for deaths due to the WBDOs. This reduces the literature-based estimate for the *Cryptosporidium* associated death toll to 93, and the range for predicted deaths becomes 94-228 (Table 2-11). And finally, because the *Cryptosporidium*-associated deaths attributed to the Milwaukee outbreak were extensively investigated by Hoxie et al. (1997), we suggest further modification of the plausible range for total deaths by limiting the *Cryptosporidium*-associated deaths to the 50 reported to the WBDOSS. This yields a range of 51 to 185 predicted deaths due to reported WBDOs over 30 years (which contains the WBDOSS reported value of 66).

2.7. EPIDEMIOLOGIC BURDEN SEVERITY MEASURES

The summary epidemiologic severity measures used for our burden analysis are presented in Table 2-12. The number of cases, hospitalizations, and deaths are used

TABLE 2-11 Modifications of the Plausible Predicted Number of WBDO Deaths Estimated from Literature-based Fatality-case Ratios		
	Low Estimate from Literature Sources	High Estimate from Literature Sources
Totals from Table 2-10	94	2,243
Using only Mead et al., fatality-case ratio for estimated case numbers for *Cryptosporidium* (because the 403,000 cases of cryptosporidiosis were estimated for Milwaukee) yielding estimate of 93 WBDO *Cryptosporidium* deaths	94	228
Using only the 50 *Cryptosporidium* deaths attributed to the Milwaukee outbreak data in the WBDOSS	51	185

TABLE 2-12 Epidemiological Burden Measures Used in the Analysis Reported Waterborne Outbreaks in Drinking Water for the 30-Year Period, 1971 to 2000		
Epidemiological Burden Measure	Value Used in the Burden Analysis	Reported or Estimated
Cases	569,962	Reported
Person-Days of Illness	4,504,933*	Estimated
Physician Visits	41,985	Estimated
Emergency Room Visits	23,575	Estimated
Hospitalizations	5,915	Reported
Deaths	66	Reported

* If 3 days duration of illness is assumed for cryptosporidiosis occurring during the Milwaukee outbreak (i.e., the median duration ascertained from survey respondents), the Person-Days of Illness value changes to 2,086,933.

as reported. Person-days ill, physician visit, and emergency room visit numbers were derived with the estimation methods described earlier in this chapter. Inaccurate reporting and paucity of data create uncertainty in the burden measures. The sensitivity of the burden estimate to uncertainty in the various burden components is examined in Chapter 6.

3. RESULTS: PROJECTED EPIDEMIOLOGIC BURDEN ESTIMATE OF REPORTED INFECTIOUS WATERBORNE OUTBREAKS BY SUMMARY CATEGORIES AND IMPACT OF THE MILWAUKEE OUTBREAK

The epidemiologic burden estimate is presented in this chapter by five summary categories: etiology, water system type, water system deficiency, time period and water source type. We conduct these analyses to identify the specific divisions within the summary categories that have been associated with the largest epidemiologic burden. Due to the magnitude of illness associated with the Milwaukee WBDO, we develop additional comparisons within the summary categories by excluding the Milwaukee WBDO. This allows trends that may be evidenced by data from the other 664 reported WBDOs to be examined.

3.1. EPIDEMIOLOGIC BURDEN BY ETIOLOGIC AGENT

Etiologic agents were identified in only 45% of reported WBDOs. Over the 30-year period, protozoans caused the most outbreaks when the etiologic agent was identified. Protozoan agents were associated with the most cases (449,925), person-days ill (4,090,423), physician visits (29,949), emergency room visits (13,093), hospitalizations (4,517) and deaths (50) (Table 3-1). The major contributors to the burden of protozoan WBDOs are *Cryptosporidium* and *Giardia* (Table 3-2). Other protozoan agents (i.e., *Cyclospora* and *En. histolytica*) were reported in only one outbreak each and contribute little to the epidemiologic burden estimate.

AGI WBDOs (i.e., outbreaks with no identified etiologic agent) were associated with the second highest burden for person-days ill, physician visits and emergency room visits; however, bacterial WBDOs were associated with more hospitalizations and deaths than AGI WBDOs (Table 3-1).

TABLE 3-1

Projected Epidemiologic Burden of Reported Infectious Waterborne Outbreaks in Drinking Water by Etiologic Agent, 1971 to 2000*

Etiologic Agent	Outbreaks	Cases	Person-Days Ill	Physician Visits	Emergency Room Visits	Hospital-izations	Deaths
AGI	365	83,493	265,120	8,822	9,426	378	1
Viruses	56	15,758	53,697	2,017	124	92	0
Bacteria	101	20,786	95,615	1,196	931	928	15
Protozoa							
Milwaukee WBDO	1	403,000	3,627,000	20,280	11,727	4,400	50
All Other WBDO	142	46,925	463,423	9,669	1,366	117	0
Total	665	569,962	4,504,854	41,985	23,575	5,915	66

* Column totals for physician visits, emergency room visits, and hospitalizations do not sum due to rounding.

TABLE 3-2

Projected Epidemiologic Burden of Reported Infectious Waterborne Outbreaks in Drinking Water by Etiologic Agent, 1971 to 2000

Etiologic Agent	Outbreaks	Cases	Person-Days Ill	Physician Visits	Emergency Room Visits	Hospital-izations	Deaths
AGI	365	83,493	265,120	8,822	9,426	378	1
Viruses							
Norovirus	26	13,100	25,139	1,086	43	10	0
SRSV (assumed to be norovirus)	1	70	9,686	6	0	0	0
Rotavirus	1	1,761	91	146	6	0	0
Hepatitis A	28	827	18,782	780	75	82	0
Bacteria							
C. jejuni	19	5,604	26,082	325	16	87	0
E. coli	12	1,529	10,537	89	7	122	4
E. coli & Campylobacter	1	781	60	45	4	71	2
P. shigelloides	1	60	210	3	0	3	0

TABLE 3-2 cont.							
Etiologic Agent	Outbreaks	Cases	Person-Days Ill	Physician Visits	Emergency Room Visits	Hospital-izations	Deaths
Salmonella non-typhoid spp.	15	3,203	17,328	186	15	82	7
S. enterica serovar Typhi	5	282	5,502	7	1	238	0
Shigella	44	9,196	31,104	533	886	301	2
V. cholerae	2	28	950	2	0	4	0
Yersinia	2	103	134	6	0	10	0
Protozoa							
Cryptosporidium							
Milwaukee WBDO	1	403,000	3,627,000	20,280	11,727	4,400	50
All Other WBDO	14	18,473	170,834	929	538	48	0
Cyclospora	1	21	228	1	1	0	0
En. histolytica	1	4	3,749	0	0	1	0
Giardia	126	28,427	292,319	8,738	827	68	0
Total	665	569,962	4,504,854	41,985	23,575	5,915	66

1 AGI = Acute gastrointestinal illness of unknown etiology
2 SRSV = Small round structured virus

Bacterial WBDOs resulted in about 25% more reported cases of illnesses than viral WBDOs (20,786 cases versus 15,758 cases). The major contributors to the burden of bacterial WBDOs were *Shigella*, *Campylobacter*, *E. coli* and non-typhoid *Salmonella* spp. (Table 3-2). When compared to viral WBDOs, bacterial WBDOs also resulted in larger estimates of person-days ill, emergency room visits, hospitalizations and deaths (Table 3-1). However, viral WBDOs resulted in almost twice as many physician visits than bacterial WBDOs. Fifty-four percent of the physician visits associated viral WBDOs are due to norovirus (Table 3-2). In viral WBDOs, over half of the person-days ill were due to Hepatitis A which accounted for only 5% of the cases attributed to viral WBDOs.

Tables 3-1 and 3-2 show that the Milwaukee WBDO is, by far, the largest WBDO reported between 1971 and 2000. Table 3-1 shows that, for each epidemiologic burden measure, the Milwaukee WBDO is greater than the corresponding burden measure, reported for all other protozoan WBDOs, all AGI WBDOs, all bacterial WBDOs and viral WBDOs. In fact, this single outbreak accounts for more cases, person-days ill, emergency room visits, hospitalizations and deaths than all other WBDOs combined.

Excluding the Milwaukee WBDO, the types of pathogens that contribute the most to individual burden measures differs from those identified when Milwaukee is included. Table 3-1 shows that protozoan WBDOs still account for more person-days ill and physician visits than any other type of pathogen. Bacterial WBDOs account for more hospitalizations and 15 of the 16 reported deaths. The AGI WBDOs account for more cases and emergency room visits than any of the specific pathogens (we note that these outbreaks are likely caused by various pathogens). Excluding the AGI and the

Milwaukee WBDOs, Table 3-2 shows that *Giardia*, *Cryptosporidium* and norovirus accounted for the most cases of reported WBDOs; *Giardia*, *Cryptosporidium* and *Shigella* accounted for the most person-days ill. If AGI and the Milwaukee WBDOs are excluded, *Giardia*, norovirus, and *Cryptosporidium* accounted for the most physician visits; *Shigella*, *Giardia* and *Cryptosporidium* accounted for most of the emergency room visits. If AGI and the Milwaukee WBDOs are excluded, three bacterial WBDOs are associated with the most hospitalizations: *Shigella, S. enterica* serovar Typhi and *E. coli.* Finally, we note that, when the Milwaukee WBDO is excluded, bacterial WBDOs accounted for most of the remaining deaths; the primary agents that caused these deaths were non-typhoid *Salmonella* spp. and *E. coli* O157:H7.[1,2]

3.2. EPIDEMIOLOGIC BURDEN BY WATER SYSTEM TYPE

In the WBDOSS, water systems are classified as community, non-community or individual (Appendix A).[3] For our projected burden estimates, all burden measures except number of outbreaks are greatest for community systems; community systems accounted for the most cases (485,844), person-days ill (4,215,965), physician visits

[1] Although most strains of *E. coli* are not pathogenic, there are a number of diarrheagenic strains. Of particular concern are the enterohemorrhagic strains such as O157:H7. The WBDOSS specifically identifies the nine *E. coli* outbreaks that have occurred since 1989 as strain O157:H7.

[2] We note that the WBDOSS does not track cases of hemolytic uremic syndrome (HUS), which has been linked to *E. coli* O157 infections. However, HUS cases have been noted in external reports describing some of the *E. coli* O157:H7 outbreaks included in the WBDOSS (Swerdlow et al., 1992; CDC, 1999c; Olsen et al., 2002).

[3] Community and noncommunity water systems are public water systems that serve >15 service connections or an average of >25 residents for >60 days/year. A community water system serves year-round residents of a community, subdivision, or mobile home park with >15 service connections or an average of >25 residents. A noncommunity water system can be nontransient or transient. Nontransient systems serve >25 of the same persons for >6 months of the year, but not year-round (e.g., factories or schools), whereas transient systems provide water to places in which persons do not remain for long periods of time (e.g., restaurants, highway rest stations or parks). Individual water systems are small systems not owned or operated by a water utility that serve <15 connections or <25 persons. Outbreaks associated with water not intended for drinking (e.g., lakes, springs and creeks used by campers and boaters, irrigation water and other nonpotable sources with or without taps) are also classified as individual systems.

(32,400), emergency room visits (16,268), hospitalizations (4,931) and deaths (62). Although non-community systems reported 75 more WBDOs than community systems (Table 3-3), all other summary measures were substantially less than those reported by community systems. Summary burden measures were the lowest for individual systems reflecting the low number of individual system outbreaks reported.

If the Milwaukee WBDO is excluded, Table 3-3 shows that the remaining community system WBDOs and the non-community WBDOs report comparable numbers of cases. While for the remaining community system WBDOs (i.e., excluding Milwaukee) we estimate more than twice as many person-days ill and nearly 40% more physician visits than non-community system WBDOs, for non-community system WBDOs we estimate nearly 50% more emergency room visits and nearly 70% more physician visits than community system WBDOs. The 253 remaining community system WBDOs report 12 deaths and the non-community system WBDOs report 4 deaths.

Communities receive their drinking water from surface waters, groundwaters or a mix of the two. Figure 3-1 shows the number of community system outbreaks that were associated with each type of water source. The figure shows that surface water sources and groundwater sources have accounted for roughly the same number of community system WBDOs. Figures 3-2 and 3-3 show that community system WBDOs that occurred in communities served by surface water systems have resulted in the largest number of person-days ill and deaths. When the Milwaukee WBDO is excluded from the analysis, WBDOs in community systems served by groundwater accounted for the remaining 12 deaths that occurred in community systems; however, groundwater

TABLE 3-3

Projected Natural Burden of Reported Infectious Waterborne Outbreaks in Drinking Water, 1971 to 2000

Water System Classification	Outbreaks	Cases	Person-Days Ill	Physician Visits	Emergency Room Visits	Hospital-izations	Deaths
Community							
Milwaukee WBDO	1	403,000	3,627,000	20,280	11,727	4,400	50
All Other WBDO	253	82,844	588,965	12,120	4,541	531	12
Non-Community	329	78,703	262,157	8,812	6,744	885	4
Individual	82	5,415	26,732	773	563	99	0
Total	665	569,962	4,504,854	41,985	23,575	5,915	66

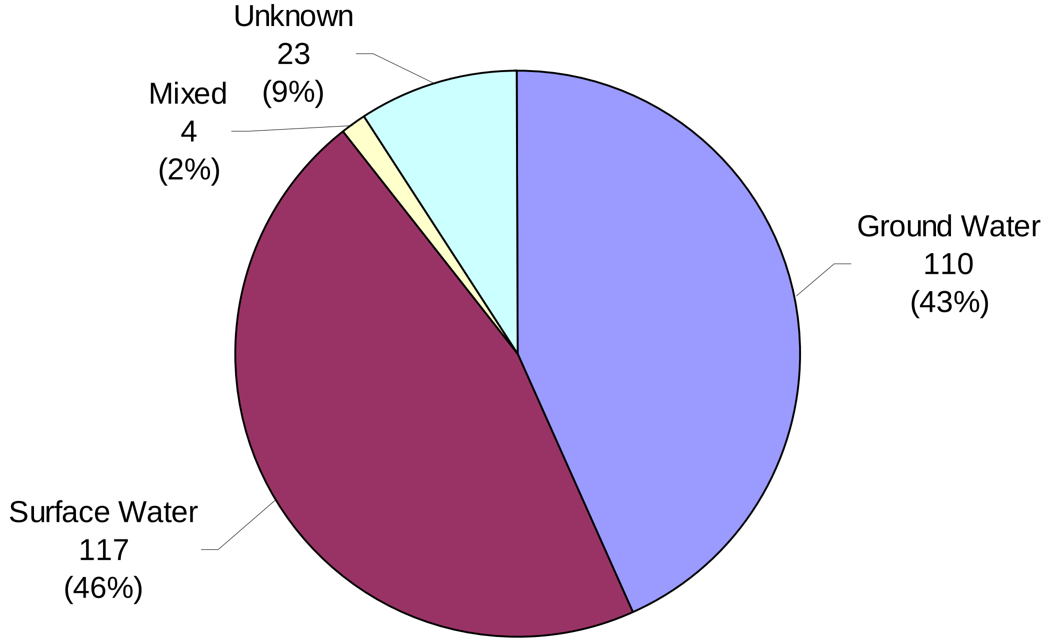

FIGURE 3-1

Number of Outbreaks for Community System WBDOs by Source Type

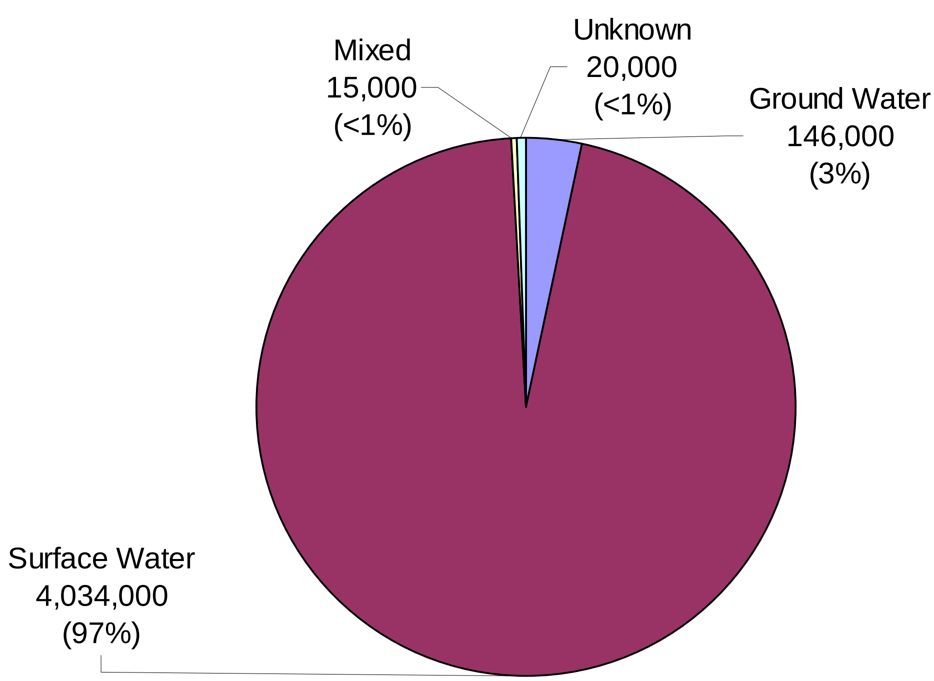

FIGURE 3-2

Number of Person-Days Ill for Community System WBDOs by Source Type

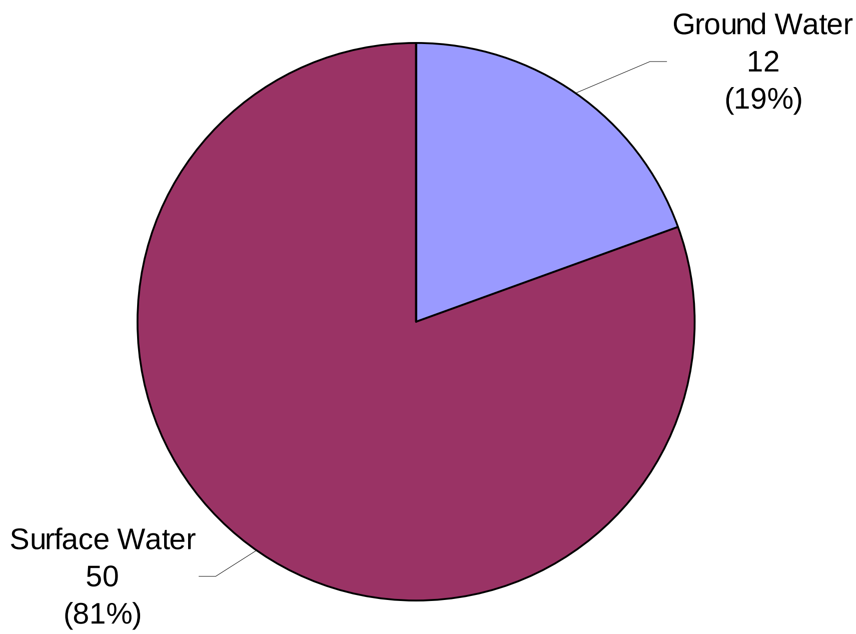

FIGURE 3-3

Number of Deaths for Community System WBDOs by Source Type*

* Mixed contamination and unknown contaminant accounted for no deaths.

sources account for only 25% of the person-days ill in community system WBDOs because the remaining surface water WBDOs account for nearly 70% of the person-days ill.

3.3. EPIDEMIOLOGIC BURDEN BY WATER SYSTEM DEFICIENCY

WBDOs are categorized in the surveillance system according to the deficiency that may have caused or contributed to the outbreak (Appendix A). The five major categories are water treatment deficiencies; distribution system deficiencies; untreated, contaminated groundwater; untreated, contaminated surface water; miscellaneous and unknown deficiencies. The most important contributor to the projected epidemiologic burden for all measures was one or more water treatment deficiencies (Table 3-4). WBDOs caused by one or more water treatment deficiencies accounted for the most outbreaks (269), cases (525,733), person-days ill (4,281,583), physician visits (36,348), emergency room visits (20,068), hospitalizations (4,980) and deaths (52). The next two most important contributors to the epidemiologic burden were distribution system deficiencies and the use of untreated, contaminated groundwater. Although more WBDOs were reported in untreated groundwater systems, the other epidemiologic burden severity measures were roughly equivalent (i.e., same order of magnitude). The lowest epidemiologic burden was associated with WBDOs caused by miscellaneous or unknown deficiencies or untreated surface water. U.S. EPA regulations now prohibit the use of untreated surface water for community and non-community water systems (U.S. EPA, 2003). Regulations pertaining to groundwater are currently under development.

TABLE 3-4

Epidemiologic Burden of Reported Infectious Waterborne Outbreaks in Drinking Water by Water System Deficiency, 1971 to 2000

Deficiency	Outbreaks	Cases	Person-Days Ill	Physician Visits	Emergency Room Visits	Hospital-izations	Deaths
Deficiency in Water Treatment							
Milwaukee WBDO	1	403,000	3,627,000	20,280	11,727	4,400	50
All Other WBDO	268	122,733	654,583	16,068	8,341	580	2
Distribution System Deficiency	83	15,305	98,314	2,311	824	201	12
Untreated Groundwater	211	22,285	83,803	2,605	2,217	602	2
Miscellaneous	41	2,053	14,873	223	193	43	0
Unknown Deficiency	23	3,372	16,570	291	173	84	0
Untreated Surface Water	38	1,214	9,711	208	100	5	0
Total	665	569,962	4,504,854	41,985	23,375	5,915	66

If the Milwaukee WBDO is excluded, Table 3-4 shows that the remaining WBDOs, caused by one or more water treatment deficiencies, account for more outbreaks, cases, person-days ill, physician visits, emergency room visits and hospitalizations than all other types of deficiencies. However, distribution system deficiencies have reported more deaths (12) than the remaining WBDOs caused by one or more water treatment deficiencies (2), untreated groundwater (2), untreated contaminated surface water (0), miscellaneous (0) and unknown deficiencies (0). While the second highest number of outbreaks, cases, physician visits, emergency room visits and hospitalizations are reported for WBDOs caused by untreated groundwater, distribution system deficiencies account for the second highest person-days ill and deaths.

The three types of deficiencies causing the fewest number of outbreaks are miscellaneous (41), untreated contaminated surface water (38) and unknown deficiencies (23); no deaths were reported for any WBDOs attributed to these deficiencies. Of these three causes of WBDOs, untreated contaminated surface waters reported the fewest numbers of cases, person-days ill, physician visits, emergency room visits and hospitalizations. Despite causing the smallest number of outbreaks, WBDOs caused by unknown deficiencies reported the most cases and hospitalizations. They also had the highest estimates of person-days ill and physician visits. We estimated more emergency room visits for WBDOs associated with miscellaneous causes than for those caused by unknown deficiencies.

Figures 3-4 through 3-8 illustrate the person-days ill associated with each etiologic agent for each type of deficiency. Figure 3-4 reveals that *Cryptosporidium*

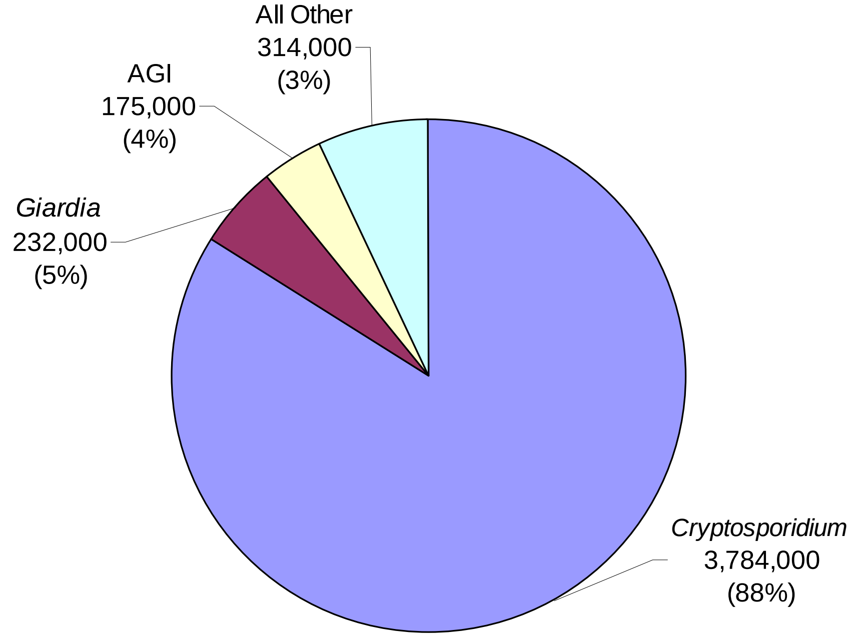

FIGURE 3-4

Person-Days Ill for Water System Deficiency in Water Treatment by Etiologic Agent*

____

* Percentages differ slightly from those listed in text due to rounding.

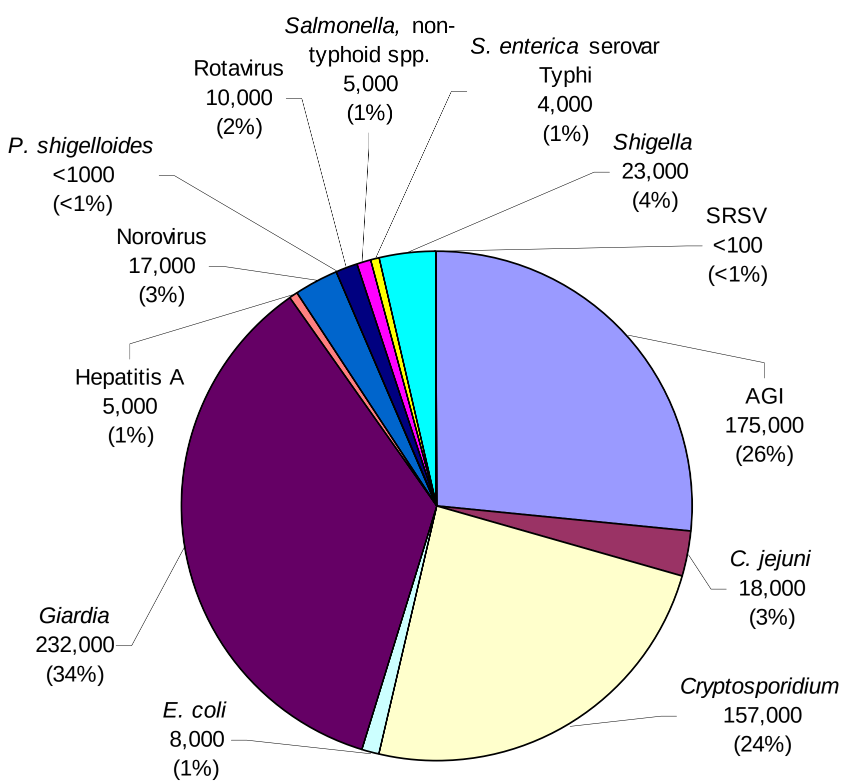

FIGURE 3-5

Person-Days Ill for Deficiency in Water Treatment WBDOs by Etiologic Agent (excluding the Milwaukee WBDO)

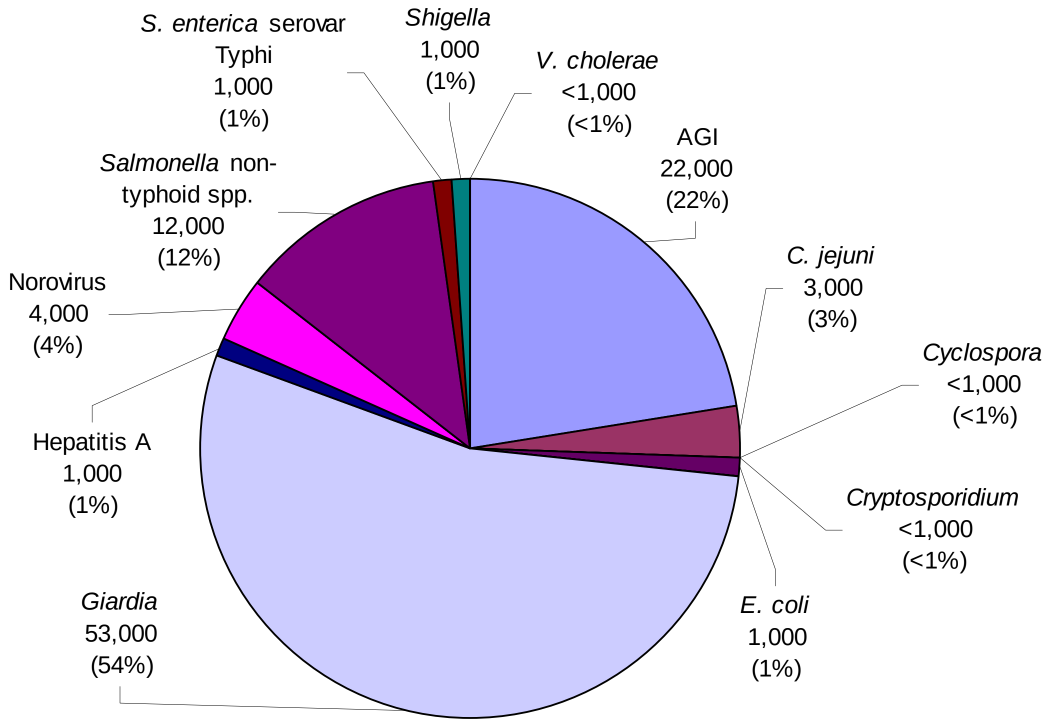

FIGURE 3-6

Person-Days Ill for Distribution System Deficiency

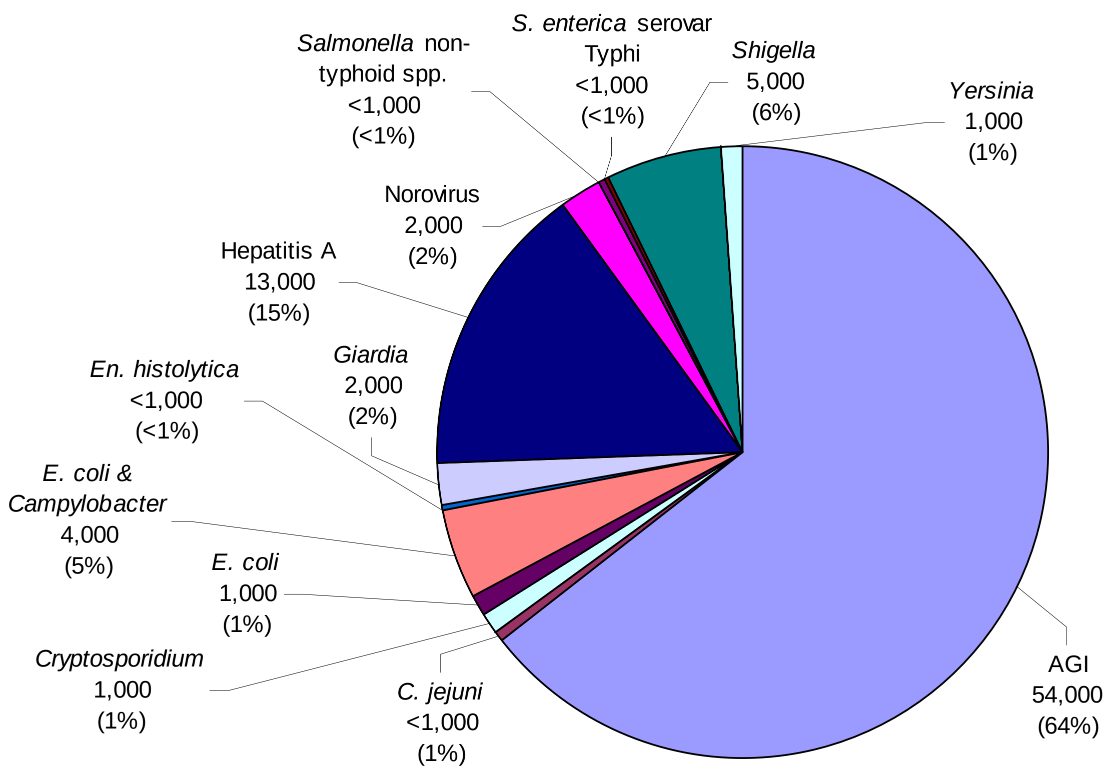

FIGURE 3-7

Person-Days Ill for Untreated Groundwater

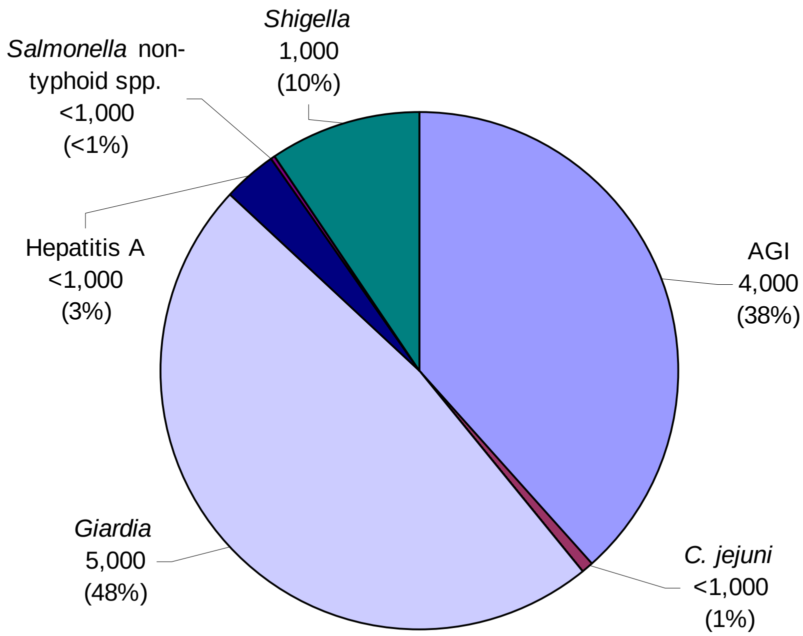

FIGURE 3-8

Person-Days Ill for Water System Deficiency in Untreated Surface Water accounts for most (88%) of the person-days ill associated with water treatment deficiencies; over 95% of these person-days associated with *Cryptosporidium* occurred during the Milwaukee WBDO. We note that this single outbreak also was associated with most of the deaths reported in the WBDOSS. Figure 3-5 reveals that, if the Milwaukee WBDO is excluded from the analysis, *Giardia* (36%), AGI (27%) and *Cryptosporidium* (24%) account for nearly 86% of the person-days ill that occurred due to water treatment deficiency. Figure 3-6 reveals that *Giardia* (54%) accounts for over half of the person-days ill for WBDOs attributed to distribution system deficiencies. Outbreaks attributed to AGI (22%) and *Salmonella* (12%) combined account for 34% of the person-days ill associated with distribution system deficiencies. Previously, we reported that outbreaks attributed to distribution system deficiencies were associated with 12 (18%) of the deaths reported in the WBDOSS. Non-typhoid *Salmonella* spp. (7) and *E. coli* (4) accounted for most of these deaths. Outbreaks associated with AGI accounted for 65% of the person-days ill when the cause of the outbreak was attributed to untreated groundwater (Figure 3-7). Outbreaks associated with Hepatitis A, the most frequently identified etiologic agent, accounted for 15% of all person-days ill. The two deaths caused by untreated groundwater were associated with an *E. coli* and *Campylobacter* outbreak.

The epidemiologic burden associated with the remaining outbreak causes reported in the WBDOSS is substantially smaller than the burden associated with treatment deficiencies, distribution system deficiencies and untreated groundwater. When the cause of the outbreak was attributed to untreated surface water, *Giardia* (46%) and AGI (38%) accounted for 84% of all person-days ill (Figure 3-8).

3.4. EPIDEMIOLOGIC BURDEN BY TIME PERIOD

The fewest number of outbreaks occurred in the 1990s, however, that decade experienced the majority of burden in all measured categories (Table 3-5) due to the Milwaukee WBDO. WBDOs that occurred in the 1990s accounted for the most cases of illness (432,195), person-days ill (3,775,241), physician visits (23,412), emergency room visits (13,834), hospitalizations (4735) and deaths (59). The majority of the cases was reported in 1993, the year of the Milwaukee WBDO (Appendix C). In 24 of the 30 years in our surveillance period, fewer than 10,000 cases were reported annually, and in 13 years, 2000 or fewer cases were reported. Since 1993, the largest number of cases reported annually in WBDOs was 2492. The annual reported and projected burden information for WBDOs is presented in Appendix C.

When the Milwaukee WBDO is excluded, the number of outbreaks, cases, person-days ill, physician visits, emergency room visits and hospitalizations decreases in each successive decade (Table 3-5). In general, across each of these measures, the largest percent change occurs between the decade of the 1980s and 1990s. Only deaths attributed to WBDOs increase in successive decades.

3.5. EPIDEMIOLOGIC BURDEN BY WATER SOURCE TYPE

Reported WBDOs in surface water systems occurred less frequently than in groundwater systems (183 versus 425), but WBDOs in surface water systems experienced a greater number of cases (457,310), person-days ill (4,058,221), physician visits (29,735), emergency room visits (14,443), hospitalizations (4,644), and deaths (50) (Table 3-6). Most of the surface water outbreaks were associated with *Giardia* (48%) or AGI (36%) (Figure 3-9). However, most of the person-days ill in

TABLE 3-5

Epidemiologic Burden of Reported Infectious Waterborne Outbreaks in Drinking Water by Decade, 1971 to 2000

Decade	Outbreaks	Cases	Person-Days Ill	Physician Visits	Emergency Room Visits	Hospitalizations	Deaths
1991 to 2000							
Milwaukee WBDO	1	403,000	3,627,000	20,280	11,727	4,400	50
All Other WBDO	144	29,195	148,211	3,132	2,107	335	9
1981 to 1990	235	63,236	342,920	6,941	4,467	391	4
1971 to 1980	285	74,531	386,772	11,632	5,274	789	3
Total	665	569,962	4,504,854	41,985	23,575	5,915	66

TABLE 3-6

Epidemiologic Burden of Reported Infectious Waterborne Outbreaks in Drinking Water by Water Source Type, 1971 to 2000

Water Source Type	Outbreaks	Cases	Person-Days Ill	Physician Visits	Emergency Room Visits	Hospitalizations	Deaths
Surface Water							
Milwaukee WBDO	1	403,000	3,627,000	20,280	11,727	4,400	50
All Other WBDO	182	54,310	431,221	9,455	2,716	244	0
Groundwater	425	105,750	407,068	11,460	8,387	1,208	16
Unknown	51	3,997	23,653	460	518	43	0
Mixed	6	2,905	15,913	330	227	20	0
Total	665	569,962	4,504,933	41,985	23,575	5,915	66

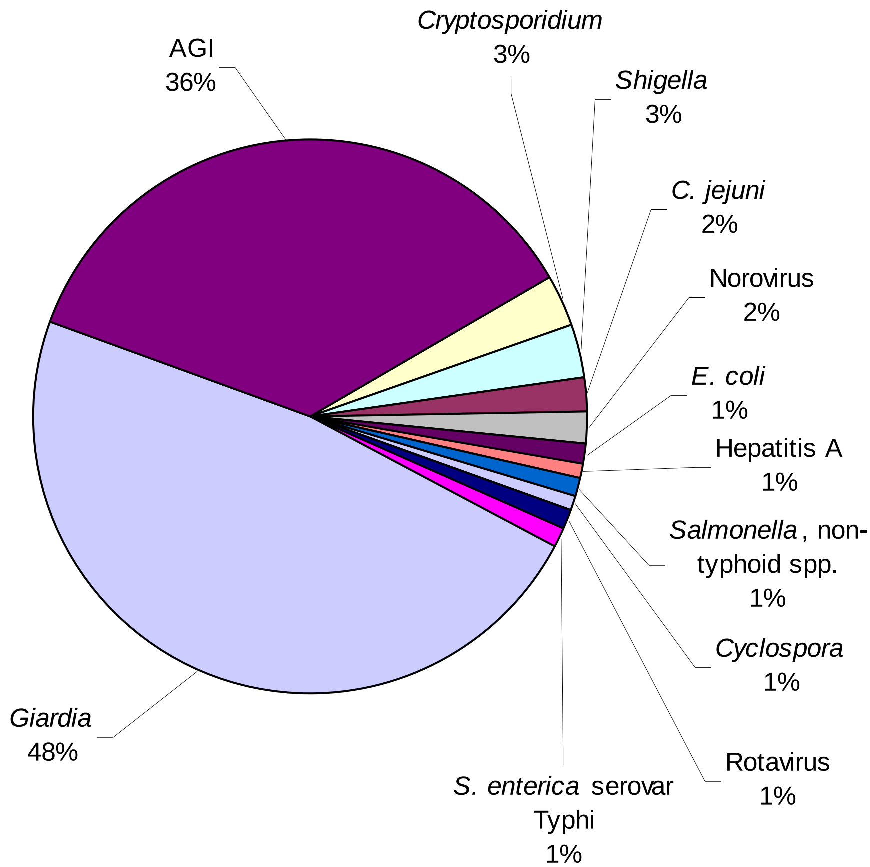

FIGURE 3-9

Pathogens Associated with WBDOs in Surface Water Systems Between 1971 and 2000 surface water outbreaks were associated with *Cryptosporidium* (92%), primarily due to the Milwaukee WBDO, which accounted for over 89% of all person-days ill associated with *Cryptosporidium* (Figure 3-10). Groundwater outbreaks were primarily associated with AGI (62%) (Figure 3-11). AGI outbreaks were responsible for the greatest number of person-days ill in groundwater systems (52%) (Figure 3-12). Unknown and mixed water sources were negligible contributors to the epidemiologic burden estimate.

3.6. OVERALL IMPACT OF MILWAUKEE CRYPTOSPORIDIOSIS OUTBREAK

The Milwaukee WBDO contributes a significant portion of the projected epidemiologic burden for reported WBDOs, and therefore, the epidemiologic burden estimates are highly sensitive to the severity measures reported in Milwaukee. This WBDO contributed 403,000 (71%) cases of illness, 3,627,000 (81%) person-days ill, 20,280 (48%) physician visits, 11,727 (50%) emergency room visits, 4,400 (74%) hospitalizations, and 50 (76%) deaths to the projected burden. Consequently, the summary burden categories associated with this WBDO (community water systems, protozoan agents, *Cryptosporidium*, water treatment deficiencies, outbreaks from 1991 to 2000 and surface water outbreaks) have the highest burden. This demonstrates the impact that a very large WBDO can have on the epidemiologic burden.

3.7. FURTHER ANALYSIS OF OUTBREAKS CAUSED BY AGI

WBDOs attributed to AGI contribute significantly to the epidemiologic burdens for the reported WBDO. Because these outbreaks could be caused by different organisms, we stratified the AGI WBDOs across source water and system type. Figure 3-13 shows that 72% of the outbreaks attributed to AGI have occurred in systems served by groundwater sources. Figure 3-14 shows that these groundwater WBDOs accounted

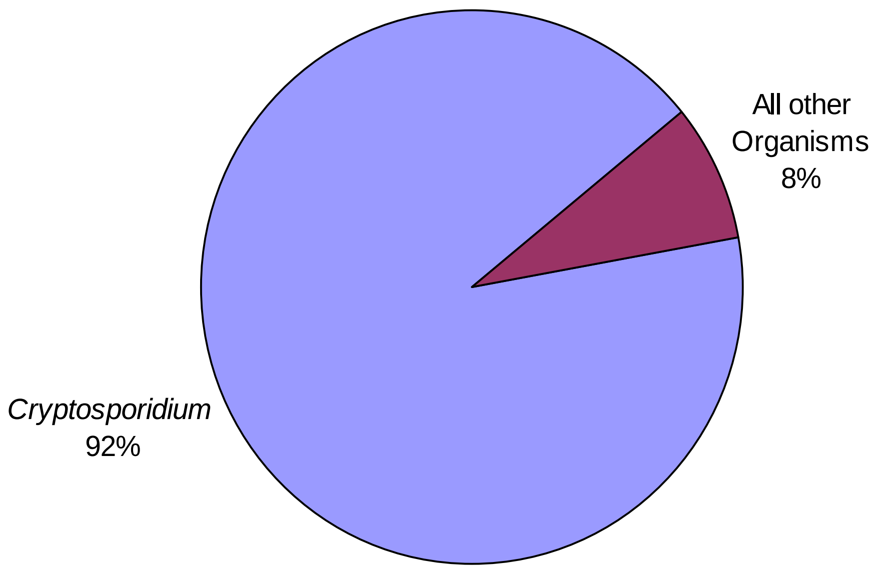

FIGURE 3-10

Pathogens Associated with Person-Days Ill in Surface Water System Outbreaks Between 1971 and 2000

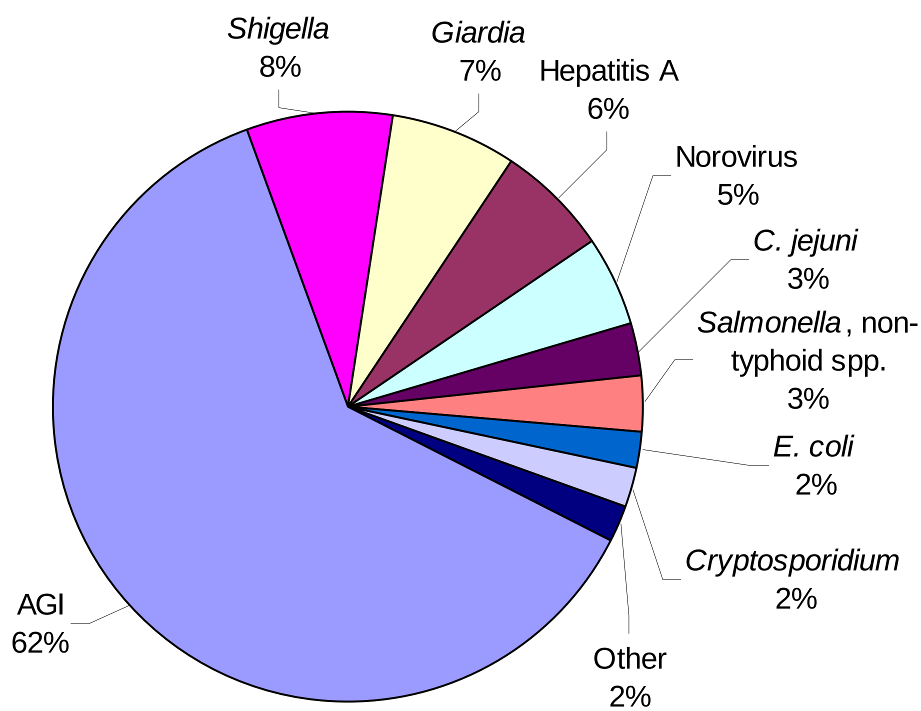

FIGURE 3-11

Pathogens Associated with WBDOs in Groundwater Systems Between 1971 and 2000

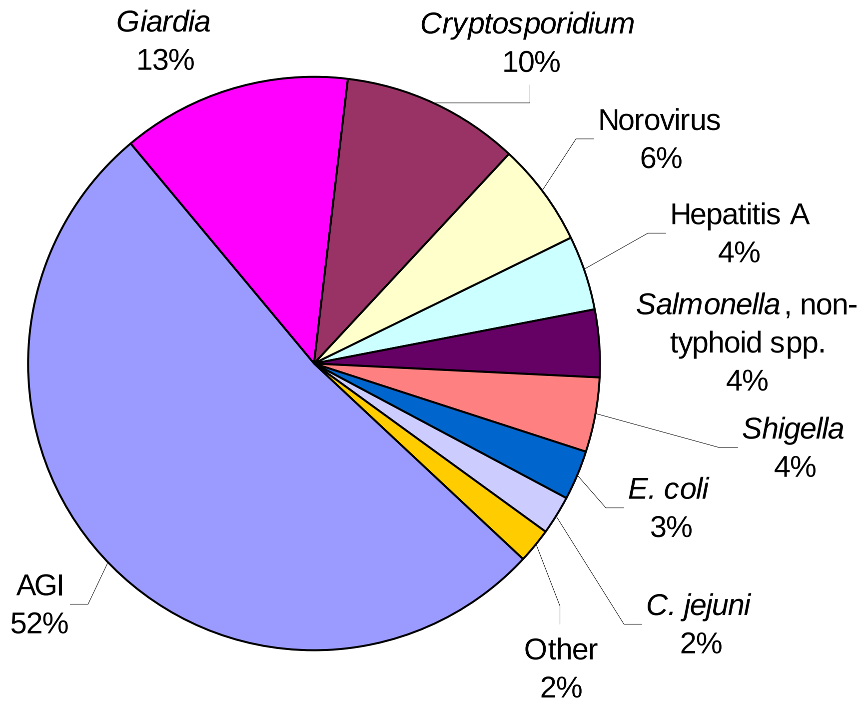

FIGURE 3-12

Pathogens Associated with Person-Days Ill in Groundwater Systems Between 1971 and 2000

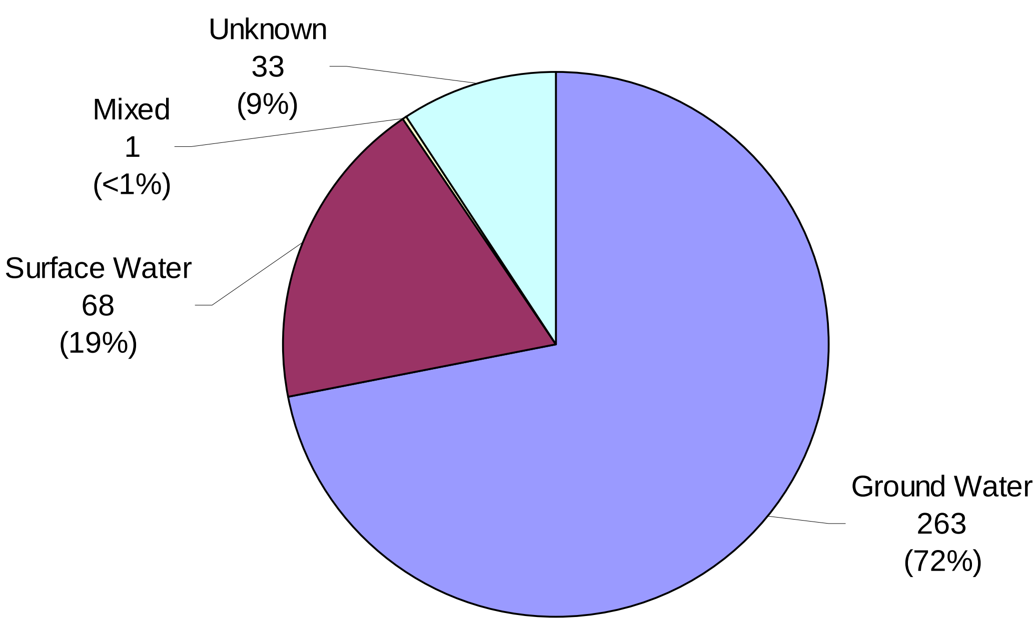

FIGURE 3-13

Number of Outbreaks for AGI WBDOs by Source Type

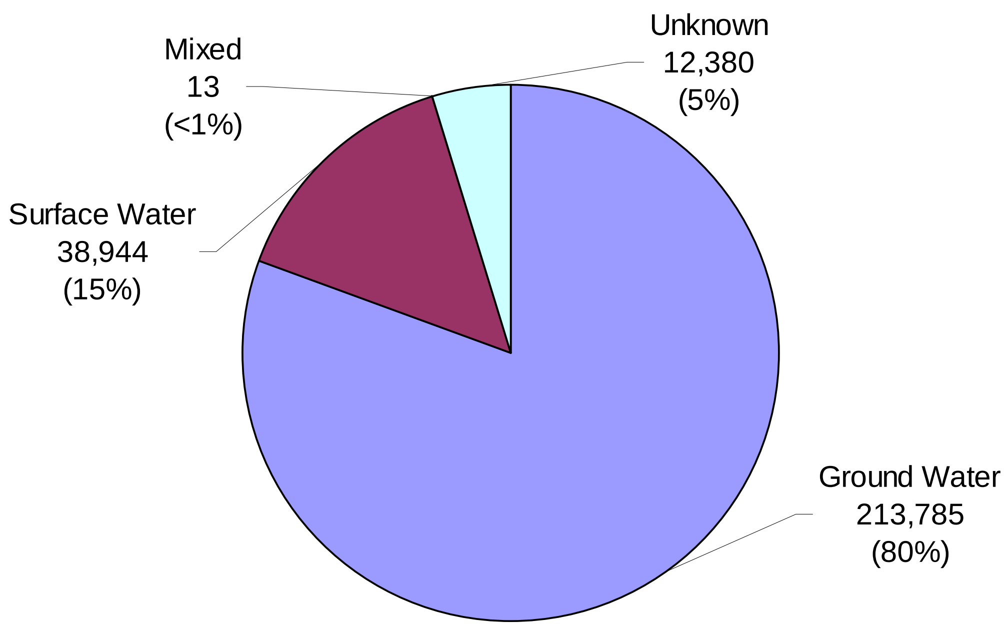

FIGURE 3-14

Number of Person-Days Ill for AGI WBDOs by Water Source Type for 81% of the person-days ill attributed to the AGI. This suggests that WBDOs occurring in groundwater sources may be caused by etiologic agents that are difficult to detect (e.g., viruses). Figures 3-15 and 3-16 show that non-community systems account for over 60% of the outbreaks and the person-days ill attributed to AGI. This suggests that it is more difficult to identify an etiologic agent in WBDOs that occur in non-community systems than those WBDOs that occur in other systems.

3.8. DISCUSSION AND CONCLUSIONS

When comparing multiple epidemiologic burden measures for the various water system categories, it is not always clear which category makes the most important contribution to the overall burden. In some analyses, one category may be an important contributor to most but not all burden measures. For example, when analyzing the projected epidemiologic burden by etiologic agent group we found that AGI WBDOs caused more outbreaks, cases, person-days illness and physician visits than bacterial WBDOs, but bacterial WBDOs caused more hospitalizations and deaths. In order to rank the various summary measures by their relative importance, a weighting approach of the burden severity measures should be considered. In Chapters 4 and 5, we present an economic weighting to the burden measures. Because the economic measures are developed using the same unit (dollars), they can be summed, allowing the various severity measures to be combined into a single severity expression—the monetary burden. The methodology for determining the monetary burden is described in Chapter 4, and a summary of the monetary burden measures for the WBDOs is provided in Chapter 5.

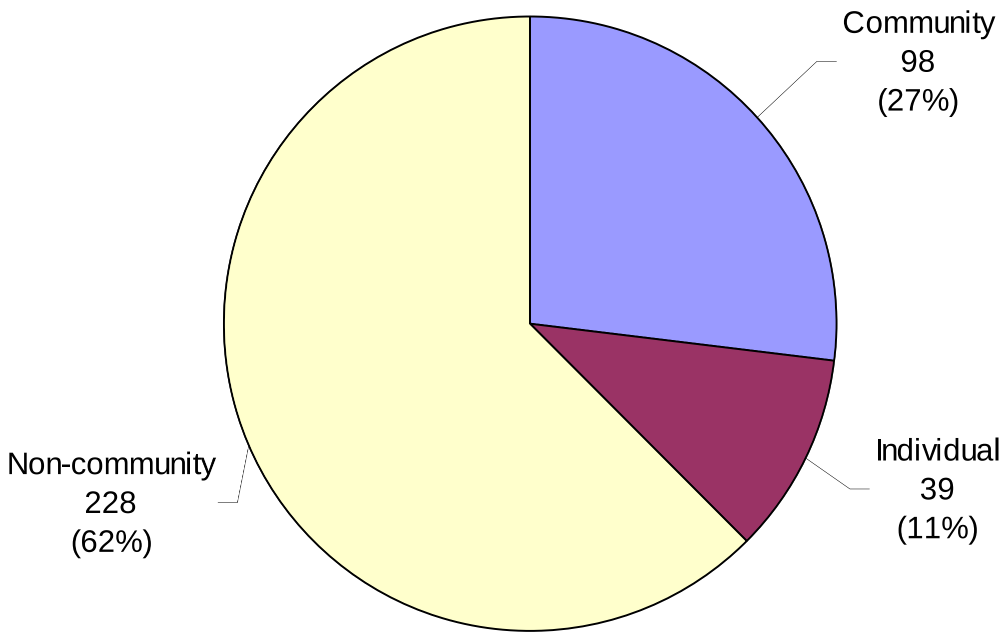

FIGURE 3-15

Number of Outbreaks for AGI WBDOs by Water System Type

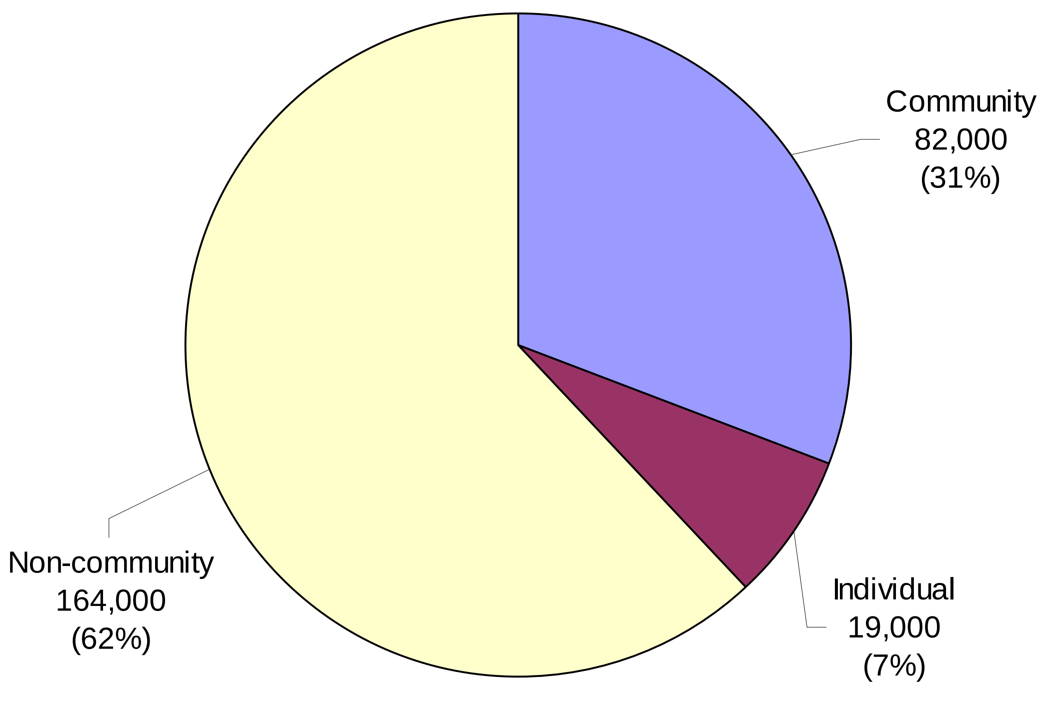

FIGURE 3-16

Number of Person-Days Ill for AGI WBDOs by Water System Type

4. ECONOMIC METHODS FOR ESTIMATING DISEASE BURDEN ASSOCIATED WITH INFECTIOUS WATERBORNE OUTBREAKS

As stated in Chapter 1, disease burden can be estimated by epidemiologic measures, summary population health measures (e.g., Disability Adjusted Life Years [DALYs]), cost-of-illness (COI) and willingness-to-pay (WTP). Disease burden measures can capture different dimensions of the impact of microbial illness, such as premature mortality, pain and suffering, economic losses to society and individuals and any other intangibles that society values. Some measures allow for comparisons of outbreaks and illnesses that impact these dimensions in different ways. Corso et al. (2003), for example, estimate the medical costs and lost productivity associated with an outbreak of cryptosporidiosis using COI. Harrington et al. (1989) and Kocagil et al. (1998) estimate lower-bound WTP[1] because they include medical costs, lost productivity, defensive or averting expenditures and, in the case of Kocagil et al., premature mortality.

In this chapter, we discuss the methods used in this report to estimate the monetary burden associated with infectious WBDOs. The approach presented is applied only to the number of reported cases for each WBDO. In Section 4.1, we describe the COI approach, including the basis of costs for self-medication, emergency room visits, hospitalizations and lost productivity (i.e., morbidity costs). In Section 4.2, we present the concept of the value of a statistical life (VSL) based on WTP values that estimates individuals' collective preferences for trade-offs between avoiding premature

[1] The results from Harrington et al. (1989) and Kocagil et al. (1998) are considered lower-bound estimates of WTP because they do not capture dimensions such as pain and suffering.

mortality and wealth. Using the COI and VSL approaches is standard practice for benefit-cost analyses in the U.S. EPA (U.S. EPA, 2000b, 2006a).

Figure 4-1 outlines the components we used to calculate the monetary burden; it also illustrates the components that we did not quantify. Additional categories of burden that are considered beyond the scope of this analysis include health effects to children and chronic illness associated with both bacterial and viral illness. The results of the COI and VSL analyses are combined to estimate the monetary burden (Chapter 5); we note that, although both measures are expressed in monetary units, human capital measures, such as COI measures, capture only a subset of the factors that WTP measures capture. COI measures are limited because they do not capture all aspects of disease burden such as pain and suffering, anxiety or lost leisure time. Expressing the burden in terms of epidemiologic units (Chapters 2 and 3) and monetary units through the COI and VSL approaches (Chapters 4 and 5) allows us to estimate the enteric disease burden associated with reported WBDOs from two different perspectives.[2] This provides an opportunity to compare the burden over time and among the various etiologic agents, water system types and system deficiencies.

4.1. ESTIMATING THE MONETARY BURDEN OF WBDO USING COST-OF-ILLNESS APPROACH

An outbreak can have a substantial economic impact on a community. Using cost estimates, such as those from Corso et al. (2003), we compare monetary burden associated with WBDOs. We then compare the monetary burden associated with

[2] Epidemiologic units are the basis of the COI estimates developed for each WBDO. Uncertainties in the estimation of the aggregated epidemiologic units will be propagated through the subsequent analysis.

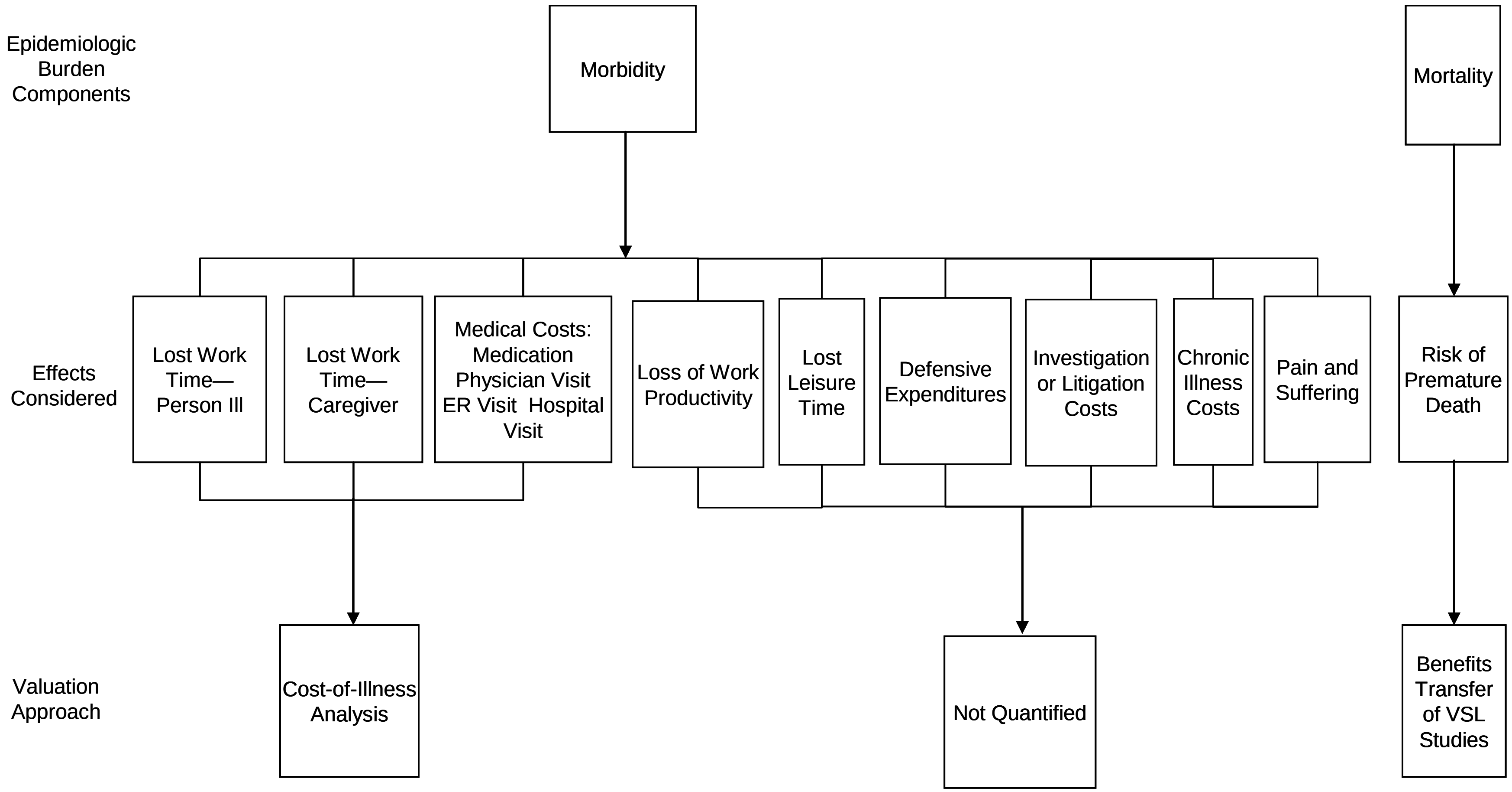

FIGURE 4-1

Illustration of the Components for Monetary Burden Calculations
(Adapted from U.S. EPA, 2000c)

different pathogens or different outbreak causes, such as treatment failure or contaminated source water. Other applications using monetary measures, such as examining the efficiency of regulations or management alternatives, typically require additional information and assumptions; these are not evaluated in this report.

The COI approach measures direct medical costs and indirect costs such as productivity losses due to temporary ailments (Rice et al., 1967). The direct medical costs include medication (Section 4.1.2), physician visits (Section 4.1.3), emergency room visits (Section 4.1.4) and hospital stays (Section 4.1.5). The loss of productivity of the average person is assumed to be days lost based on a fraction of the duration of illness (Section 4.1.6). Traditionally, in COI studies, the primary cost associated with premature mortality is based on an individual's expected future earnings had they remained alive until some average age of death. This estimate is consistent with other components of the COI, in that it represents the monetary costs incurred by society; however, it is not consistent with Agency protocol (Whitman, 2003). Therefore, the value of a premature mortality is based on the VSL (see Section 4.2).

The COI of the j^{th} outbreak could be calculated by summing the costs of each case, dependent on cost related to self-medication (e.g., over-the-counter medications), physician visits, emergency room visits, hospitalizations and productivity losses of the ill person and their caregiver(s) (e.g., family members). However, because this type of data is not recorded in the database, calculating COI at the individual level is not feasible. Alternatively, the COI of the j^{th} outbreak can be estimated by using mean values reported for other outbreaks (Equation 4-1).

$$COI_j = (N_{ill} x C_{SM}) + (N_{PV} x C_{PV}) + (N_{ER} x C_{ER}) + (N_H x C_{HP}) + \sum_{s=1}^{3} [(P_{PI_S} x D_s x L_D) + (P_{PCG_S} x D_s x L_D)] \qquad \text{(Eq. 4-1)}$$

$$= SM_j + PV_j + ER_j + H_j + PI_j + PCG_j$$

where:

N_{ill} = Number of ill persons

C_{SM} = Mean cost of self medication (2000$)

N_{PV} = Number of physician visits

C_{PV} = Mean cost of physician visit (2000$)

N_{ER} = Number of emergency room visits

C_{ER} = Mean cost of emergency room visit (2000$)

N_H = Number of hospitalizations

C_{HP} = Mean cost of hospitalizations for specific pathogens (2000$)

P_{PI} = Percent days lost for each severity category (based on fraction of duration) for ill persons multiplied by number of persons in each severity category

P_{PCG} = Percent days lost for each severity category (based on fraction of duration) for caregivers multiplied by number of persons in each severity category

D = Duration (Days)

L_D = Value of a lost day (2000$)

s = Severity categories: mild, moderate and severe

SM_j = Total cost of self medication purchased to treat illness associated with the jth outbreak (2000$)

PV_j = Total cost of physician visits associated with the j^{th} outbreak (2000$)

ER_j = Total cost of emergency room visits associated with the j^{th} outbreak (2000$)

H_j = Total cost of hospitalizations associated with the j^{th} outbreak (2000$)

PI_j = Productivity losses of ill persons associated with the j^{th} outbreak (2000$)

PCG_j = Productivity losses of caregivers associated with the j^{th} outbreak (2000$)

By using estimated mean values for the morbidity costs,[3] this equation does not capture important sources of cost variability between cases and across different outbreaks (see Table 4-1).

The definitions and calculations from Equation 4-1 are based largely on the economic analysis of the 1993 Milwaukee *Cryptosporidium* outbreak (Mac Kenzie et al., 1994; Corso et al., 2003). The majority of COI measures (SM, PV, ER, PI and PCG) were estimated using the Corso et al. approach. Corso et al. (2003) based their measures of COI on a telephone survey of Milwaukee residents by Mac Kenzie et al. (1994), which allowed for the categorization of cases based on severity. Corso et al. (2003) also collected primary data from the medical and financial records of 11 hospitals in Milwaukee. They did not include averting behavior costs or defensive expenditures (e.g., purchasing a water filter or bottled water), costs of epidemiologic investigation or litigation nor did they consider pain and suffering. Therefore, the COI estimates for this analysis do not either. Not including these costs or considerations is warranted because

- the Milwaukee outbreak represents almost 71% of all cases of illness reported in WBDOs during 1971-2000
- the economic analysis is fairly recent
- the analysis is presented in sufficient detail for our use.[4]

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[3]All cost estimates are adjusted to 2000 U.S. dollars (2000$) using the consumer price index (CPI) for medical services. The CPI is the average change in prices over time for a market basket of goods and services (in this case medical goods and services such as prescription drugs and medical supplies, physicians' services, and hospital services). It is typically used to measure inflation, but can also be used to develop comparisons using constant monetary units (U.S. Department of Labor, 2000).

[4] For analyses of specific outbreaks, values which are specific to the area of the outbreak should be used if available. Analyses do not exist for these WBDOs, so we note a potential bias in the burden estimate.

TABLE 4-1

Parameter Estimates from Cost-of-Illness Studies (cost estimates adjusted to 2000$)

Components	Corso et al. (2003)	U.S. EPA's LT2ESWTR (2006a)	Kocagil et al. (1998)	Harrington et al. (1991)	Zimmerman et al. (2001)
Pathogen	*Crypto-sporidium*	*Crypto-sporidium*	*Crypto-sporidium*	*Giardia*	Rotavirus
Physician visits	$58	$58	--	$88	$62[a]
Hospital visits	$8,142	$7,937[b]	$12,419[c]	$244	$2,487[d]
ER visits	$289	$289	$197[e]	$66	--
Medication	$12, $91[f]	$91	$2[g]	$68[h]	---
Lost work time	$206[i]	$88[j]	--	$876[k]	--
Loss of work productivity	--	$27[j]	--	$905[k]	--
Length of illness (days)	--[l]	4.7, 9.4, 34[m]	--	42 (mean)	--
Work loss days	1.3, 3.8, 13.5[n]	1.3, 3.8, 13.5[n]	--	6.3, 12.7[o]	--

[a] Median cost of rotavirus-associated outpatient visit

[b] Based on Corso et al. (2003), 71% of severe illness patients that visited the ER were hospitalized. U.S. EPA (2006a) removed these ER costs from their hospitalization cost estimate.

[c] Medical expenditures for severe illness (i.e., hospitalization)

[d] Median cost of rotavirus-associated hospitalization

[e] Medical expenditures for physician visit or ER visit

[f] Cost of medication prescribed after seeking healthcare—moderate illness and severe illness, respectively (Self-medication prior to seeking healthcare can be found in Table 4-4.)

[g] Over-the-counter medications

[h] Medication costs associated with medical treatment

[i] Average cost of productivity losses across illness severity (mild, moderate and severe) where average productivity losses were $113, $413 and $1409 in 1993$, respectively This value also includes the value of those who are not employed.

[j] Per day value includes both lost work time and lost unpaid work time and is calculated from U.S. EPA's enhanced COI analysis. Loss of work productivity is calculated as a portion (30%) of lost work time.

[k] Average per confirmed case evaluated at the implicit after-tax wage rate of the unemployed, homemakers and retirees equal to $6.39 per hour (average after-tax wage rate of employed) (Harrington et al., 1989, 1991).

[l] Corso et al. (2003) does not estimate a mean duration of illness for moderate or severe illness. The duration of illness for mild cases was estimated as 4.7 days.

[m] The U.S. EPA (2006a), using Monte Carlo analysis, calculated the mean duration of illness for moderate and severe illness. Corso et al. (2003) only has an estimate for mild cases.

[n] Mild, moderate and severe illness, respectively

[o] Employed and homemakers, respectively

TABLE 4-1 cont.					
Components	Cohen et al. (1978) Foodborne	ERS Calculator (2006) Foodborne	AGA (2001) Foodborne	AGA (2001) Chronic diarrhea	Ezzati-Rice et al. (2004)
Pathogen	*Salmonella*	*Salmonella*	All	All	All expenses
Physician visits	$699[p]	$93	$114	$123	--
Hospital visits	$8,785[q]	$11,966	$5,848[r]	$2,453[r]	$5,195, $10,917[s]
ER visits	--	$262	$350	$255	$315, $594[s]
Medication	--	0	--	--	--
Lost work time	$1,421[t]	$191,$186, $185[u]	--	--	--
Loss of work productivity	--	--	--	--	--
Length of illness (days)	--	--	--	--	--
Work loss days	12, 3[v]	4.5, 1.6, 0.5[w]	--	--	--

[p] Study states that approximately 68% of $222 for outpatient visits (ER or office) is for medical care and the remainder is accounted for by estimates of lost productivity (based on assumption). Therefore, medical portion is $151 in 1976$.
[q] Includes physician fees, operations and medication
[r] Comprised of two parts: (1) facility costs and (2) physician visits and procedures
[s] Median, mean, respectively, per person with expense
[t] Study determined each worker's daily salary and multiplied it by days of work lost (average of both employed and caregivers).
[u] Average daily wage rate depending on severity Severity categories, hospitalized, sought medical care, and did not seek medical care, respectively, were assumed to have different age distributions leading to different average daily wage rates.
[v] Average lost work days for employed patients (102 of 117 employed patients) and caregivers (39 of 102), respectively
[w] Hospitalized, sought medical care and did not seek medical care, respectively.

Specific assumptions are highlighted in each section where the Corso et al. analysis was used. This COI analysis is limited because we estimate disease burden using the same process regardless of year; we assume that medical treatment administered and costs for gastrointestinal illnesses have remained constant across years.

For comparison purposes, general economic analyses are reported in Table 4-1. Besides Corso et al. (2003), we present nine other COI studies. U.S. EPA (2006a), expanding on Corso et al., analyzed the effects of the Long Term 2 Enhanced Surface Water Rule. Kocagil et al. (1998) focused on Lancaster County, PA to estimate the value of preventing a *Cryptosporidium* contamination event. Harrington et al. (1991) examined the economic losses caused by waterborne giardiasis in Luzerne County, PA. Zimmerman et al. (2001) calculated costs for rotavirus-associated hospitalizations and outpatient visits for privately insured children during the period of 1993 to 1996. Cohen et al. (1976) analyzed the economic costs of a foodborne outbreak of salmonellosis (due to non-typhoid *Salmonella* spp.) in Colorado. The Economic Research Service (ERS, 2006) of the U.S. Department of Agriculture calculated the costs of different foodborne illnesses. We present their cost estimates for salmonellosis. The last three studies are not specific to any particular pathogen. The American Gastrointestinal Association (AGA) calculated the economic costs for common disorders. We included only two of the gastrointestinal disorders: foodborne and chronic diarrhea. Ezzati-Rice et al. (2004) presented the costs of health care based on the Medical Expenditure Panel Survey; we included their per person expenditures for hospital visits and ER visits. All cost estimates are adjusted to 2000$ using the consumer price index (CPI) for medical services. Our analysis could have utilized U.S. EPA's expanded analysis of Corso et al.

(2003); however, for simplification purposes and to utilize the duration-of-illness estimates from the WBDOSS, we decided to proceed with the approach in Corso et al.

4.1.1. Severity Classification. In this analysis, physician visits, emergency room visits, hospitalizations and deaths are surrogate measures for the severity of illness in reported WBDOs (Table 4-2). We use the same measures of severity that Corso et al. (2003) used in their Milwaukee WBDO analysis. Because the WBDOs reported in the surveillance system do not identify cases of illness by severity categories of mild, moderate and severe, this introduces additional uncertainty into the COI estimates.

TABLE 4-2

Illness Severity Definitions

Category	Definition
Severe Illness	Hospitalizations + Deaths
Moderate Illness	Physician Visits + ER Visits
Mild Illness	All reported cases that are not moderate or severe

The unit of reporting in the WBDOSS is an outbreak; therefore, it is not possible to match severity measures at the individual case level or distinguish whether there is an overlap in reported physician visits, emergency room visits, hospitalizations and deaths. For example, some individuals who visit a physician or emergency room may also require hospitalization. Thus, in some outbreaks, using the severity definitions in Table 4-2, there is a slight overestimation of severe illnesses. Since the numbers of physician visits, emergency room visits, hospitalizations and deaths are relatively small compared to the total number of cases, this slight overestimation likely has minimal impact on the COI analysis (see Chapter 6). In addition, the number of mild, moderate or severe cases does not exceed the total number of cases reported for any outbreak.

Table 4-3 shows the distribution of reported cases in reported WBDOs by the three severity categories. The distribution of protozoan illnesses in WBDOs by severity categories was similar to the distribution reported by Corso et al. in the Milwaukee *Cryptosporidium* outbreak. The distribution of mild, moderate and severe cases of viral WBDOs and all WBDOs in reported outbreaks was fairly similar to the cases of protozoan WBDOs. This provides some support to using the Milwaukee data for the COI analysis. The distribution of AGI shows a greater percentage of moderate cases than the other groups. The reported bacterial WBDOs have a greater percentage of severe cases than the other etiologic groups (Table 4-3). Thus, we probably underestimated the burden for bacterial and AGI WBDOs based on this COI approach.

4.1.2. Costs of Self Medication (SM). For an outbreak, the cost of SM is the total cost of over-the-counter medications for mild, moderate and severe illness (e.g., anti-nausea, anti-diarrheal medications and electrolyte replacement therapy). Corso et al. (2003) obtained information from medical charts about the percentage of moderately and severely ill individuals who self medicated prior to seeking healthcare during the Milwaukee outbreak. Corso et al. assumed that the percentage of mild cases (30%) that self medicated was similar to that for moderate cases of illness. The SM cost for mild illness prior to seeking healthcare was an assumption made by Corso et al.

In the COI analysis, we use the percentage of cases that self medicate and the estimated SM costs reported in Corso et al. (Table 4-4). We calculate the SM cost by

TABLE 4-3

Distribution of Cases Using Estimated Severity Measures for Monetary Burden

Severity Classification	AGI		Viruses		Bacteria		Protozoa		All WBDOs	
	Cases	Percent	Cases	Percent	Cases	Percent	Cases	Percent	Cases	Percent
Mild	65,048	78	13,634	87	17,718	85	402,318	89	498,718	88
Moderate	18,066	22	2,032	13	2,125	10	43,040	10	65,263	11
Severe	379	0	92	1	943	5	4,567	1	5,981	1
Total	83,493	100	15,758	100*	20,786	100	449,925	100	569,962	100

* Rounding error, column does not total to 100

TABLE 4-4

Estimated Cost of Self Medication*

Item	Mild	Moderate	Severe	Notes
% Self Medication	30%	30%	29%	Corso et al. (2003)
Cost of Self Medication (1993$)	$5.73	$5.92	$6.74	Corso et al. (2003)
Cost of Self Medication (2000$)	$7.40	$7.65	$8.79	

* SM = N_{Mild} x $7.40 x 0.3 + N_{Mod} x $7.65 x 0.3 + N_{Sev} x $8.79 x 0.29
where:

N_{Mild} = Number of mild cases
N_{Mod} = Number of moderate cases
N_{Sev} = Number of severe cases

multiplying the number of illnesses in each severity category by the corresponding SM cost and the percent that self medicated. The total SM cost for a WBDO is the sum of self medication costs for mild, moderate and severe cases. These calculations are based on an assumption that the distribution of persons who self medicate and the SM costs incurred during the Milwaukee *Cryptosporidium* outbreak are similar to the distribution of persons who self medicate and the SM costs incurred during WBDOs caused by other etiologies.

4.1.3. Cost Associated with Physician Visit (PV). The costs associated with a physician visit include the professional fee and any prescribed medication (not SM cost). Our PV analysis is based on the Corso et al. (2003) economic analysis of the 1993 Milwaukee *Cryptosporidium* WBDO. We assumed that the cost of a PV is similar for cases in WBDOs of *Cryptosporidium* and other etiologies. Cost estimates of PV are updated to 2000 dollars using the CPI for medical care (Table 4-5). Information about physician visits is not requested on the WBDO report form (CDC 52.12) but is reported for 4% of the reported WBDOs.

4.1.4. Cost Associated with Visiting an Emergency Room (ER). The cost of an ER visit includes the costs of the ER, attending physician, ambulance and prescribed medication. An ER visit is not considered a hospitalization. If an ER visit results in a hospital admission, then the visit is also counted as a hospitalization. Information on ER visits is not requested on the WBDO report form (CDC 52.12) and is only reported in 2% of the outbreaks. Thus, the number of ER visits is likely under reported in the WBDOSS, and the corresponding costs associated with these cases as reported would also be underestimated. ER visit costs are based on Corso et al. (2003). We assumed

TABLE 4-5 Estimated Cost of Physician Visits*		
Item	**Cost**	**Notes**
Cost of Physician Visit (1993$)	$45.00	Corso et al. (2003)
% Prescribed Medication	54%	Corso et al. (2003) Moderate Illness
Cost of Prescribed Medication	$8.91	Corso et al. (2003) Moderate Illness
Estimated Cost of Prescribed Medication per Physician Visit	$4.81	(0.54 x $ 8.91)
Estimated Cost of Physician Visit (1993$)	$49.81	$45.00 + $4.81
Cost of Physician Visit (2000$)	$64.50	

* PV = Number of Physician Visits x $64.50

that the costs of a visit, ambulance and prescribed medicine and the percentage of cases requiring an ambulance (16%) and medication (48%) are similar for WBDOs of *Cryptosporidium* and other etiologies. The ER cost estimate is updated to 2000 dollars using the CPI for medical care (Table 4-6).

4.1.5. Cost Associated with Hospital Stay (H). Hospitalization costs are based on the 1997 Nationwide Inpatient Sample data by Health Care Utilization Project (HCUP, 1997). The Nationwide Inpatient Sample is a statistically valid sample of hospital discharges, diagnoses and charges for over 7 million hospital stays in the United States in 1997. Individual discharges were selected based on the occurrence of specific ICD-9 codes among the first three diagnoses listed on the hospital discharge report. Observations were analyzed for specific pathogens and groups of pathogens, and the HCUP reported the total hospitalization charges for selected pathogens or categories. Since total hospital charges were developed for specific etiologies and included the natural range of symptom severities for selected pathogens, all stages of disease severity should be captured.

For the COI analysis, we considered the number of reported and estimated hospitalizations for each WBDO and the average charge per hospitalization (Table 4-7). When estimates were not available or not reported for a specific pathogen, appropriate pathogens were grouped. For AGI outbreaks, we used hospitalization charges from “Diarrhea and Gastroenteritis, Undetermined Agent,” ICD codes 001-009 (excluding 3.2 and 6.2), 558.9, 787.91.

TABLE 4-6

Estimated Cost of Emergency Room Visits*

Item	Cost	Notes
Cost of Emergency Room Visit (1993$)	$224.00	Corso et al. (2003)
Percent Requiring Ambulance	16%	Corso et al. (2003) Severe Illness
Cost of Ambulance (1993$)	$228.00	Corso et al. (2003) Severe Illness
Estimated Cost of Ambulance per Emergency Room Visit (1993$)	$37.16	(0.16 x $228.00)
Percent Requiring Prescription Medication	48%	Corso et al. (2003) Severe Illness
Cost of Prescription Medication (1993$)	$70.52	Corso et al. (2003) Severe Illness
Estimated Cost of Prescription Medication per Emergency Room Visit (1993$)	$33.85	(0.48 x $ 70.52)
Total Estimated Emergency Room Visit Cost per Emergency Room Visit (1993$)	$295.01	$224.00 + $37.16 + $33.85
Total Estimated Emergency Room Visit Cost per Emergency Room Visit (2000$)	$382.02	

*ER = Number of ER Visits x $382.02

TABLE 4-7

Estimated Charges per Hospitalized Case*

Disease or Etiologic Agent	ICD Codes	Mean Charge (2000$)
Bacterial infections	Calculated	$7,836.34
Yersinia	8.44	$9,677.97
Typhoid	002	$16,172.96
Shigellosis	004	$6,781.94
Other *Salmonella* infections	003 (excluding 3.2)	$9,825.80
E. coli	8.0	$8,605.38
Cholera	001	$5,752.38
Campylobacter	8.43	$8,027.91
Other virus unspecified	088	$4,351.20
Norovirus	8.63	$4,518.06
Rotavirus	8.61	$3,919.09
Calicivirus	8.65	$1,885.95
Adenovirus	8.62	$11,538.71
Protozoan infections	Calculated	$9,093.80
Cryptosporidium	7.4	$13,886.10
Giardia	7.1	$7,257.03
Diarrhea and Gastroenteritis, undetermined agent	001-009 (excluding 3.2 and 6.2), 558.9, 787.91	$7,603.87

* H = Number of Hospitalizations x Hospitalization Charge for Specific Pathogen or Pathogen Group x 0.4

Using the CPI for medical care, we updated HCUP information for hospitalization charges in 1997 dollars to 2000 dollars. Next, we multiplied the hospital charges by the national case-weighted cost-to-charge ratio of 0.4 (CMS, 2004).

4.1.6. Cost Due to Loss in Productivity. Productivity losses can arise from decreased production at work and decreased household production due to illness, and we considered productivity losses for two groups:

- Ill person who recovers (PI)
- Caregiver(s) for ill person (PCG).

Productivity losses can potentially have two components: complete days lost and lost productivity while working (i.e., reduced hours or working at less than full capacity). We only calculate the value of a complete day lost (see Figure 4-1). Therefore, we assume that individuals, once they return to work, do not have reduced hours and are working at full capacity even though the illness is still occurring (i.e., Table 4-8 shows the difference between days lost from work by severity). This differs from U.S. EPA (2006a), which based results on Harrington et al. (1991), who found that employees worked at approximately a 30% capacity once they returned to work. We decided not to estimate the lost productivity while working because our calculation for complete days lost does not easily provide an estimate of lost productivity days by severity classification. This suggests that we are underestimating productivity losses.

Grosse (2003) estimated average earnings for each age and gender group in which earnings were comprised of two broad components: wages/fringe benefits and household production. The wage components included salary income, overtime pay, bonus pay and self-employment earnings based on the Current Population Survey

TABLE 4-8

Productivity Losses by Severity for Ill Persons and Caregivers for Waterborne Outbreaks

Category	Mild	Moderate	Severe
Mean Days Lost for Work, Ill Persons (Corso et al., 2003)	1.3	3.8	13.5
Mean Days Lost for Work, Caregivers (Corso et al., 2003)	0.1	1.3	3.9
Mean Days Lost for Work, Ill Persons / **Median Duration** of Outbreak*	14.4%	42.2%	150.0%
Mean Days Lost for Works, Caregivers / **Median Duration** of Outbreak*	1.1%	14.4%	43.3%

* The rates of productivity loss shown are for a WBDO with a median duration of 9 days.

(CPS, 2001). Fringe benefits included health insurance and retirement pay. Household production included a number of valued activities, such as cleaning, cooking, home and auto maintenance, child care and child guidance, for which individuals are typically not compensated. Grosse assumed that the average person works 250 days per year and that household services need to be performed every day. Combining the data for men and women, Grosse (2003) estimated the value of a lost day of primary activity to be $144/day[5] (2000$) using the following formula:

Value of a lost day = (Annual Earnings/250) + (Annual Household Services/365) (Eq. 4-2)

We used this estimate in all calculations of PI and PCG.[6]

4.1.6.1. Productivity Losses for Ill and Caregiver (PI, PCG) — For persons who are ill and recover, we estimated time lost from work for both ill persons and their caregivers (Table 4-8). We based the distribution of productivity losses on the analyses by Corso et al. (2003). Corso et al. categorized cryptosporidiosis cases into three groups based on information gathered during a random phone survey done by the City of Milwaukee Health Department. Categorization into mild, moderate or severe depended on the type of medical care received and days of productivity lost for the ill and their caregivers. Due to limited reported data, Corso et al. estimated the days of productivity lost for caregivers with severe illness cases assuming that caregivers were

[5]Harrington et al. (1991) estimate productivity losses at $42.82/day (2000$), which is more than $100 lower than our estimate. We attribute this partially to their average duration. They estimated a mean productivity loss of $730 (1984$), with an average duration of 41.6 days. They suggest that their duration appears extraordinarily long compared to other *Giardia* outbreaks. Mean productivity loss was calculated by adding value of workdays lost and loss of productivity. This mean loss is $17.55/day (1984$) of illness.

[6]The difference between U.S. EPA's traditional and enhanced COI for this particular calculation is the value of lost unpaid work time for the traditional COI, which is half the value of the enhanced COI. Other approaches to estimate the value of a day lost are available (e.g., see U.S. EPA, 2006a), which calculates the value of a lost work day as a fraction of a full day, 3.5 hours). When combining both lost work time and lost unpaid work time, the estimate of $144 is still $67 and $55 higher than U.S. EPA (2006a) traditional and enhanced COI, respectively.

needed for 50% of the duration of hospitalization for the ill person. Productivity losses for the ill and their caregivers were determined for the other WBDOs by multiplying the rates for each illness severity by the reported or estimated median duration for each WBDO (Table 4-8). For these other non-Milwaukee WBDOs, we used information from the WBDOSS to obtain actual or estimated values for the median duration for the various etiologic agents.

For each outbreak, we calculated cost due to complete days lost of productivity for both the ill person and caregiver by the following equations:

$$PI = [(N_{mild} \times R_{mild}) + (N_{mod} \times R_{mod}) + (N_{sev} \times R_{sev})] \times D \times L_D \qquad \text{(Eq. 4-3)}$$

$$PCG = [(N_{mild} \times R_{mild}) + (N_{mod} \times R_{mod}) + (N_{sev} \times R_{sev})] \times D \times L_D \qquad \text{(Eq. 4-4)}$$

where:

N = Number of cases

D = Median duration of illness

R = Rate of days lost for work based on illness duration (Table 4-8)

L_D = Value of a lost day = $144/day (2000$).

To compute the lost productivity costs from Table 4-8, we assume

- productivity losses are always some constant fraction of the duration of illness based upon severity grouping
- other waterborne pathogens have a similar rate of productivity loss to median duration of illness as *Cryptosporidium.*

We are uncertain how representative these ratios are for assessing the severity of other pathogens. Additional studies are needed to test the validity of these assumptions.

4.2. USING WILLINGNESS-TO-PAY MEASURE TO VALUE PREMATURE MORTALITY: VALUE OF STATISTICAL LIFE

The VSL approach is used to estimate the value of a WBDO fatality in a separate calculation (although we combine the COI estimates with the value of a WBDO fatality for the total monetary burden estimate). VSL measures an individual's WTP for a change in the risk of dying (Freeman, 1993). For example, suppose 10,000 individuals are willing to pay $5 each for an intervention that would reduce the risk of dying by one in 1,000,000. The VSL for this group would equal $5,000,000 for one less death per year. If 1,000,000 individuals were willing to pay $5 for an intervention that would reduce the risk of dying by two in 1,000,000, then the VSL would be $2.5 million (i.e., $5 million divided by two). VSL is not a component of the traditional COI approaches, which are usually limited to the costs incurred in caring for the ill and production lost to morbidity and premature mortality. Due to a paucity of data and empirical studies, the VSL is assumed to be independent of age and weights all deaths the same. Thus, the VSL is rooted in the economic tradition of "consumer sovereignty" (i.e., individuals are the best judges for their own well-being) representing the trade-off between changes in wealth and the probability of survival in a period of time (Hammitt, 2000). In the U.S. EPA, societal WTP is the standard approach to estimating a dollar value on mortality benefits of environmental regulations (U.S. EPA, 2000a).

The U.S. EPA (2000a) recommends a mean VSL estimate of $4.8 million (1990 dollars), and the Office of Water used this value after an adjustment for real income growth and inflation for the disinfectants and disinfection by-products rule, the proposed groundwater rule and the interim enhanced surface water rule. The benefit transfer of

VSL studies, updated to 2000 dollars, results in an estimate of $6.43 million (see Chapter 1).

$$\text{VSL} = \text{Number of Deaths} \times \$6.43 \text{ Million} \qquad \text{(Eq. 4-5)}$$

4.3. ESTIMATING THE MONETARY BURDEN OF THE WATERBORNE OUTBREAKS

The monetary burden (2000$) presented in Table 4-9 is based on the methodology described in Sections 4.1 and 4.2 and the epidemiologic burden measures developed in Chapters 2 and 3 for the WBDOs that occurred from 1971 to 2000. Using a COI approach, we calculate the burden of the morbidities associated with the WBDOs to be approximately $186 million. Based on the VSL approach, we estimate the burden of the premature mortalities associated with the WBDOs to be valued at approximately $424 million (70% of the total burden). The largest cost of morbidity is lost productivity of the ill person (66% of total COI) while hospitalization costs and lost productivity of the caregiver follow in impact (16% and 11% of total COI, respectively). Following the approach described in this chapter, Chapter 5 presents comparisons of the monetary burden by different summary categories.

TABLE 4-9 Projected Monetary Burden of Infectious Waterborne Outbreaks in Drinking Water, 1971 to 2000		
Burden Measure	Monetary Burden* (2000$)	Percent of Total Monetary Burden
Self Medication	$1,272,000	<1
Physician Visits	$2,708,000	<1
Emergency Room Visits	$9,006,000	2
Hospitalizations	$29,936,000	5
Ill Productivity Losses	$123,357,000	20
Caregiver Productivity Losses	$19,721,000	3
Total COI	$186,000,000	30
Value of Statistical Life	$424,380,000	70
Total	$610,380,000	100

* The estimate of monetary burden does not include loss of work productivity, lost leisure time, pain and suffering, defensive expenditures, investigation or litigation costs, or chronic illness costs (see Figure 4-1). In addition, the burden estimate does not include the specific health effects to children.

5. RESULTS: MONETARY BURDEN ESTIMATE OF REPORTED INFECTIOUS WATERBORNE OUTBREAKS BY SUMMARY CATEGORIES AND IMPACT OF THE MILWAUKEE OUTBREAK

In this chapter, we evaluate differences in monetary burden by etiology, water system type, water system deficiency, and water source type. We identify the specific categories that have been associated with the greatest burden. Stratifying by water source type and treatment deficiency, we compare the monetary burden among different pathogens. Because of the effect of the Milwaukee WBDO on the epidemiologic burden measures, the overall summary and category specific monetary burden associated with Milwaukee will always be the most dominant in the following comparisons. We also consider how the Milwaukee WBDO affects the overall monetary burden by comparing the results with and without it. Our analyses demonstrate how this large outbreak of waterborne cryptosporidiosis can affect the overall and category-specific monetary burden (Section 5.6). All monetary values are adjusted to 2000$.

As noted in previous chapters, WBDO reporting is voluntary and the surveillance data may reflect the available resources for the detection and investigation of outbreaks and laboratory capabilities for identifying the etiologies. Readers should consider that mortality is more heavily weighted than morbidity measures in our monetary burden estimates and that burden differences for a specific etiology or water system type may reflect reporting differences (see section on WBDO surveillance system limitations in Appendix A).

5.1. MONETARY BURDEN BY ETIOLOGY

Protozoan agents account for most of the monetary burden (Table 5-1) and the most cases, person-days ill, physician visits, emergency room visits, hospitalizations,

TABLE 5-1 Monetary Burden of Infectious Waterborne Outbreaks in Drinking Water, 1971 to 2000, by Etiology (Pathogen Group)	
Etiologic Agent Type	Monetary Burden[a]
AGI	$21,537,000
Viruses	$3,252,000
Bacteria	$105,225,000
Protozoa	$480,366,000[b]
Total	$610,380,000

[a] All estimates in 2000$.
[b] Monetary Burden of Milwaukee WBDO - $461,148,000 or 96% of total monetary burden for Protozoa.

and deaths (Table 3-2). *Cryptosporidium* is the major contributor to the monetary burden of protozoan WBDOs (Table 5-2). Although other protozoan agents (i.e., C*yclospora* and *En. histolytica*) contribute relatively little to the monetary burden estimate, *Giardia* contributes 29% of the monetary burden for protozoan WBDOs; however, if the Milwaukee WBDO is excluded, *Giardia* contributes 71%.

The monetary burden associated with WBDOs attributed to bacterial agents is approximately 80% smaller than the WBDOs attributed to protozoan agents (Table 5-1). Non-typhoid *Salmonella* spp. account for approximately 44% of the monetary burden attributed to bacterial pathogens (Table 5-2). AGI WBDOs were generally associated with the second highest epidemiologic burden for several measures including person-days ill, physician visits, and emergency room visits, but bacterial WBDOs were associated with more hospitalizations and, more importantly from the monetary burden perspective, 14 more deaths than AGI WBDOs (Table 3-2). This large number of deaths associated with bacterial pathogens explains the change in ranking between the monetary and epidemiologic burden estimates for AGI and bacterial WBDOs. If the Milwaukee WBDO is excluded from the analysis, then the monetary burden associated with the bacterial WBDOs ($105 million) and AGI WBDOs ($22 million) would rank higher than the protozoan WBDOs ($19 million).

5.2. MONETARY BURDEN BY WATER SYSTEM TYPE

Water systems are classified as community, non-community, or individual as defined in Appendix A. Community systems had the largest monetary disease burden between 1971 and 2000 (Table 5-3), 13 times larger than the burden associated with non-community systems and nearly 300 times larger than the burden associated with

TABLE 5-2

Monetary Burden of Infectious Waterborne Outbreaks in Drinking Water, 1971 to 2000, by Etiology (Specific Pathogens)

Etiologic Agent	Monetary Burden
AGI	
AGI	$21,537,000
Viruses	
Hepatitis A	$2,137,000
Norovirus	$830,000
Rotavirus	$282,000
SRSV (assumed to be norovirus)	$3,000
Bacteria	
Salmonella non-typhoid spp.	$45,931,000
E. coli	$26,591,000
Shigella	$15,254,000
E. coli & Campylobacter	$13,298,000
S. enterica serovar Typhi	$2,866,000
C. jejuni	$1,098,000
Yersinia	$150,000
P. shigelloides	$19,000
V. cholerae	$18,000
Protozoa	
Cryptosporidium	$466,659,000*
Giardia	$13,692,000
En. histolytica	$9,000
Cyclospora	$6,000
Total	$610,380,000

* Monetary Burden of Milwaukee WBDO - $461,148,000 or 99% of total monetary burden for *Cryptosporidium.*

TABLE 5-3 Monetary Burden of Infectious Waterborne Outbreaks in Drinking Water, 1971 to 2000, by Water System Classification Type	
Water System Classification	Monetary Burden
Community	$565,047,000[a]
Non-Community	$43,422,000
Individual	$1,910,000
Total	$610,380,000[b]

[a] Monetary Burden of Milwaukee WBDO - $461,148,000 or 82% of total monetary burden for community systems.
[b] Burden estimates do not sum to total due to rounding.

individual systems. The monetary burden for the Milwaukee WBDO, which is a community system, is estimated at $461 million. Figure 5-1 shows that, for WBDOs occurring in community water systems, the monetary burden is largest for those systems using surface water sources. If the Milwaukee outbreak is excluded from the analysis, community system WBDOs still have the highest monetary burden estimate, but the contribution of non-community systems to the total remaining monetary burden increases dramatically. Excluding the Milwaukee WBDO, non-community system WBDOs resulted in more emergency room visits and more hospitalizations than community systems. Differences in premature mortality (12 deaths in community systems versus four deaths in non-community systems), explain why the monetary burden for the community systems without the Milwaukee WBDO is still significantly larger than the estimate for the non-community systems. If the Milwaukee WBDO is excluded, the monetary burden in WBDOs occurring in community water systems using groundwater ($84 million; see Figure 5-1) is greater than the burden in community water systems using surface water sources ($18 million).

5.3. MONETARY BURDEN BY WATER SYSTEM DEFICIENCY

From the perspective of water system deficiency, the most important contributor to the monetary burden was one or more water treatment deficiencies (Table 5-4). The Milwaukee WBDO was attributed to a water treatment deficiency. The next two most important contributors were distribution system deficiencies and the use of untreated, contaminated groundwater. If the Milwaukee WBDO is excluded from the analysis, then distribution system deficiencies become the most important contributor to the monetary

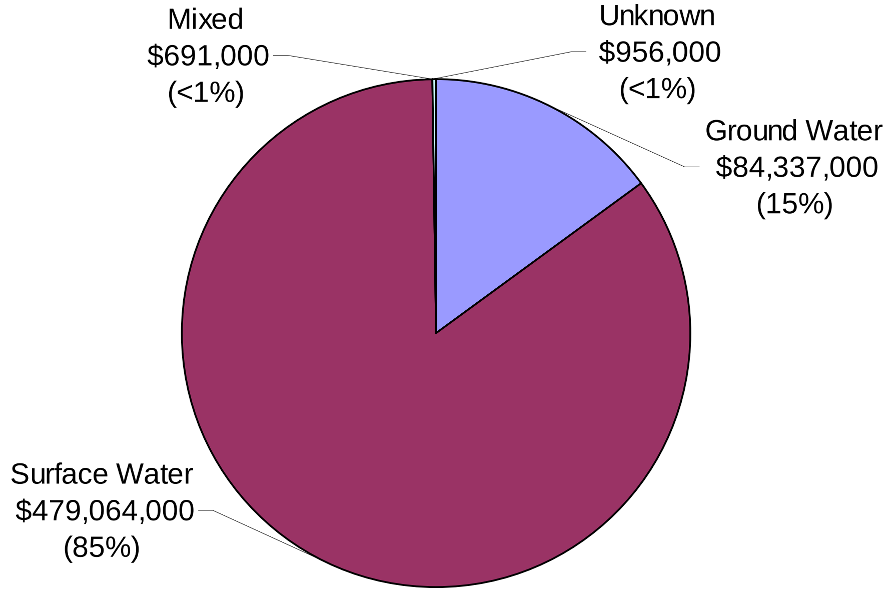

FIGURE 5-1

Monetary Burden for WBDOs in Community Water Systems by Type of Source Water

TABLE 5-4

Monetary Burden by Water System Deficiency, 1971 to 2000

Deficiency	Monetary Burden
Deficiency in Water Treatment	$505,341,000[a]
Distribution System Deficiency	$82,595,000
Untreated Groundwater	$19,991,000
Miscellaneous	$764,000
Unknown Deficiency	$1,220,000
Untreated Surface Water	$468,000
Total	$610,380,000[b]

[a] Monetary Burden of Milwaukee WBDO - $461,148,000 or 91% of total monetary burden for water treatment deficiencies.
[b] Burden estimates do not sum to total due to rounding.

burden. The smallest burden was associated with WBDOs caused by miscellaneous, unknown deficiencies, and untreated surface water.

Figures 5-2 through 5-7 show the monetary burden associated with each etiologic agent for each type of deficiency. In Chapter 3, we developed similar comparisons for person-days ill and deaths. Figure 5-2 shows that *Cryptosporidium* accounts for most (92%) of the monetary burden associated with water treatment deficiencies; 99% of this burden is associated with Milwaukee *Cryptosporidium* WBDO, in which 50 deaths occurred. Water treatment deficiencies that resulted in WBDOs caused by *Shigella* (3%), *Giardia* (2%), and AGI (2%) account for 7% of the remaining monetary burden. If the Milwaukee WBDO is excluded, then water treatment deficiencies that resulted in WBDOs caused by *Shigella, Giardia,* and AGI account for most of this monetary burden (Figure 5-3). Figure 5-4 shows that non-typhoid *Salmonella* (55%) and *E. coli* (31%) account for 86% of the monetary disease burden attributed to distribution system deficiencies. Although *Giardia* accounted for most of the person-days ill associated with WBDOs caused by distribution system deficiencies, non-typhoid *Salmonella* (55%) and *E. coli* outbreaks were associated with 7 and 4 deaths, respectively. The outbreak associated with both *E. Coli* and *Campylobacter* accounted for 67% of the monetary disease burden when the cause of the outbreak was attributed to untreated groundwater (Figure 5-5). AGI outbreaks are associated with only 16% of this monetary burden. Recall that AGI and Hepatitis A outbreaks were associated with the most person-days ill associated with WBDOs occurring in untreated groundwater, but that two deaths were associated with the *E. coli* and *Campylobacter* outbreak.

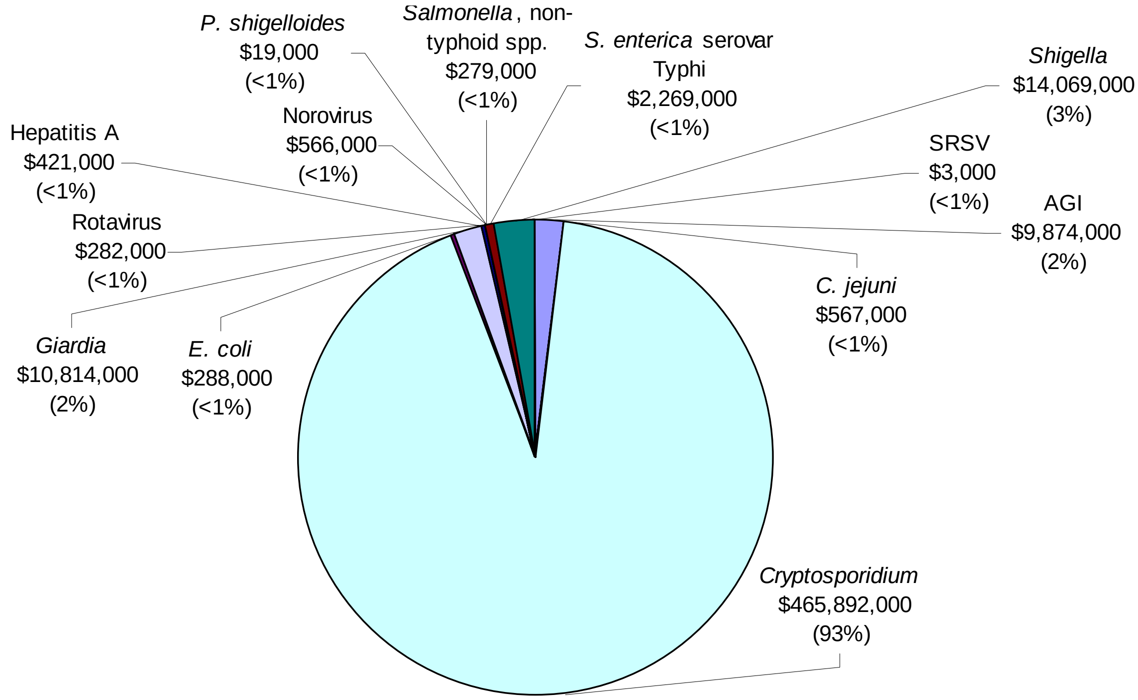

FIGURE 5-2

Monetary Burden for WBDO Caused by Water Treatment Deficiency by Etiologic Agent

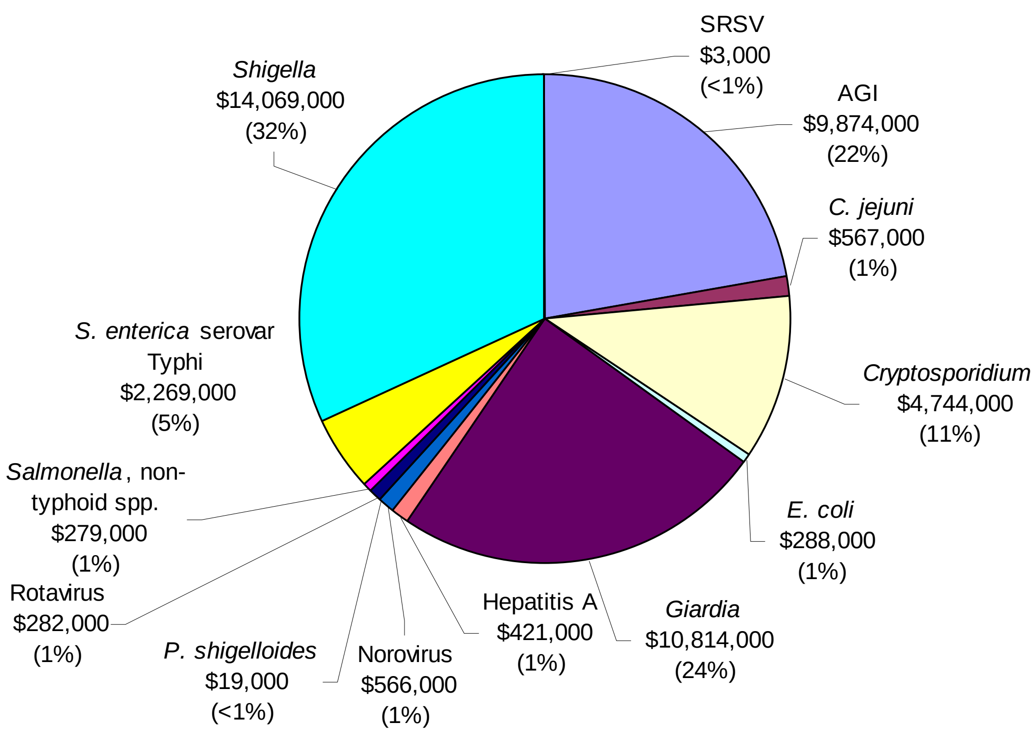

FIGURE 5-3

Monetary Burden for WBDO Caused by Deficiency in Water Treatment by Etiologic Agent (without the Milwaukee WBDO)

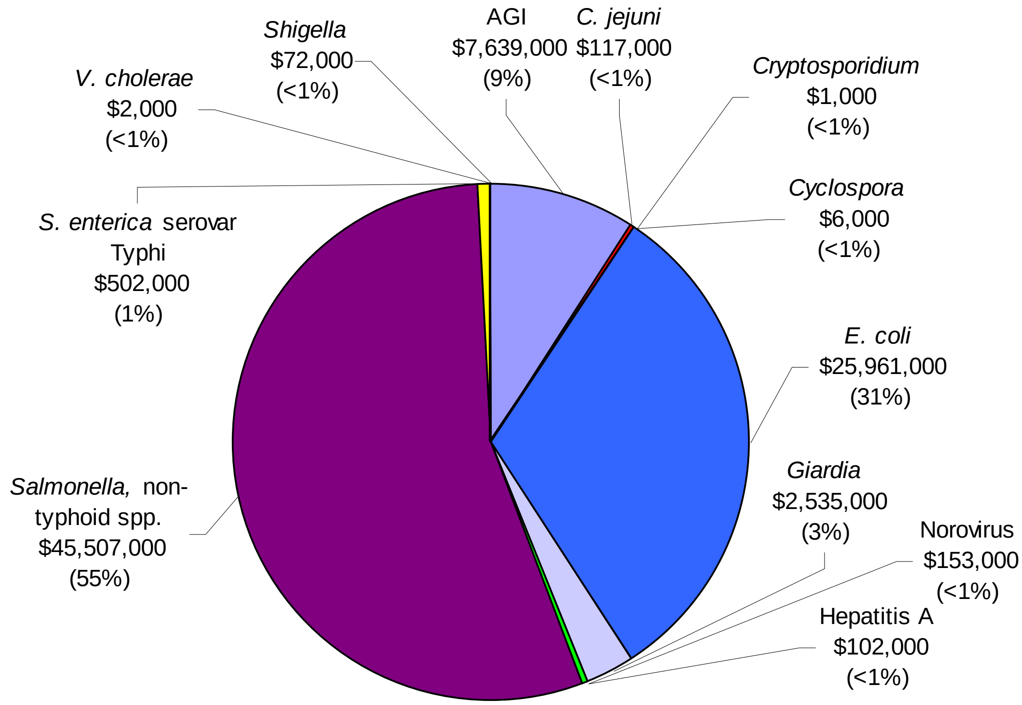

FIGURE 5-4

Monetary Burden for WBDO Caused by Deficiency Distribution System by Etiologic Agent

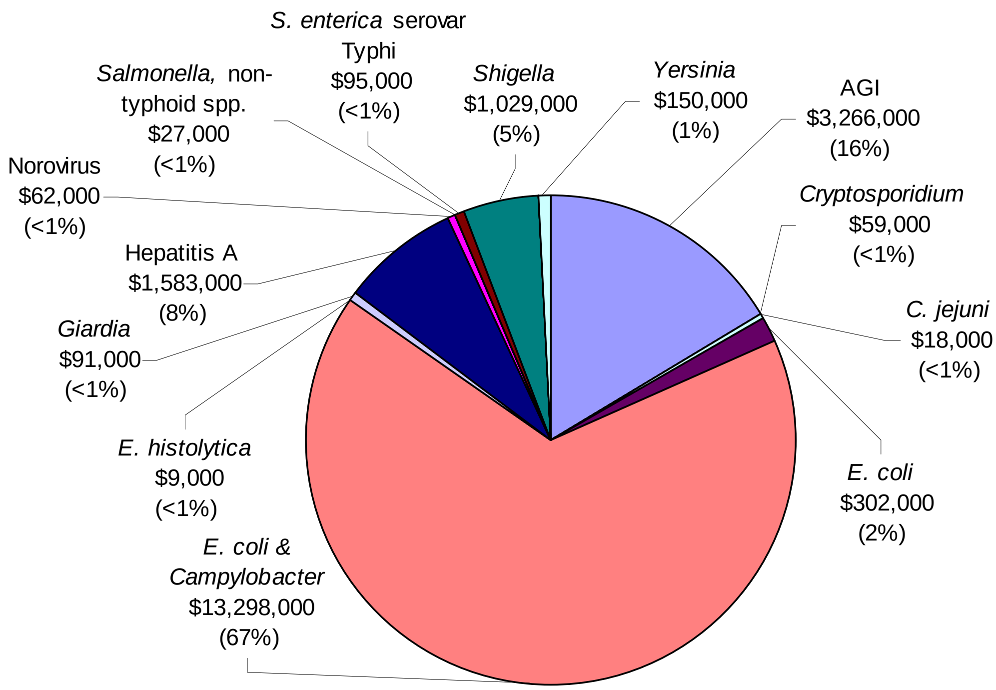

FIGURE 5-5

Monetary Burden for WBDO Caused by Untreated Groundwater by Etiologic Agent

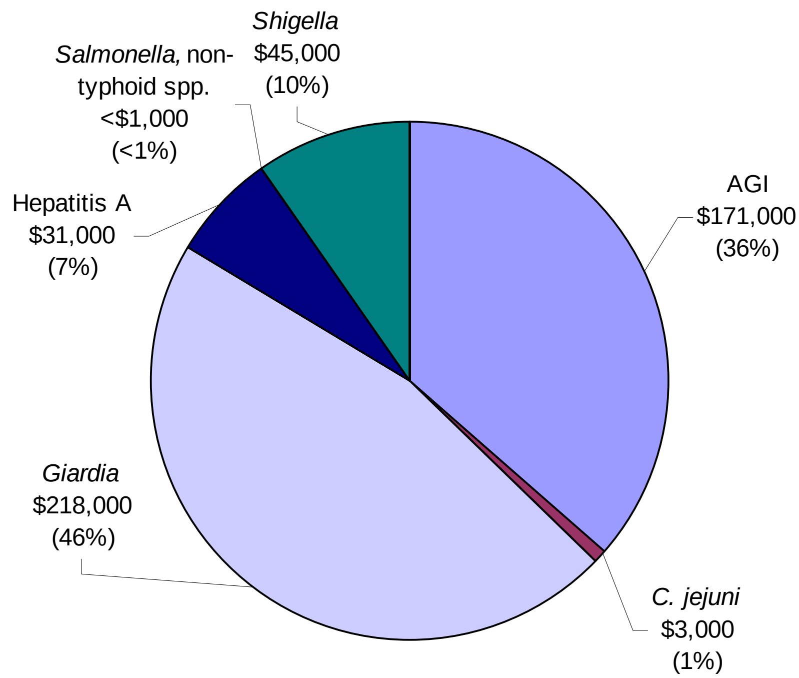

FIGURE 5-6

Monetary Burden for WBDO Caused by Untreated Surface Water by Etiologic Agent

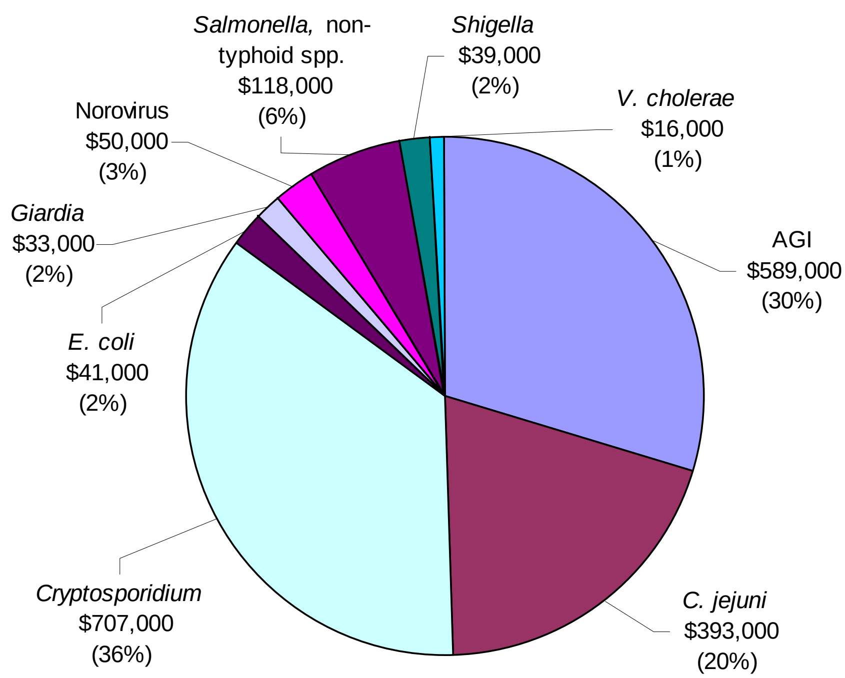

FIGURE 5-7

Monetary Burden for WBDO with Unidentified or Miscellaneous Causes by Etiologic Agent

The monetary burden associated with the remaining outbreak causes reported in the WBDOSS is substantially smaller than the burden associated with treatment deficiencies, distribution system deficiencies and untreated groundwater. Figure 5-6 reveals that, when the cause of the outbreak was attributed to untreated surface water, *Giardia* (47%) and AGI (36%) accounted for 83% of the monetary burden; the same etiologic agents also accounted for most of the person-days ill associated with untreated surface waters. Figure 5-7 suggests that, if the deficiency was not identified or categorized as miscellaneous, then *Cryptosporidium* (36%), AGI (30%) and *Campylobacter* (20%) account for 85% of this monetary burden.

5.4. MONETARY BURDEN BY TIME PERIOD

Differences in the detection and reporting of WBDOs during the 30-year period are not considered in the analysis. The WBDO surveillance system is voluntary and any trends may reflect differences in reporting and investigation of WBDO. Consequently, the following data should be interpreted cautiously.

Although the fewest number of outbreaks occurred during the 1990's, that decade dominates the monetary burden (Table 5-5) because the Milwaukee WBDO occurred in 1993. The monetary burden associated with WBDOs in the 1990's is more than ten times the monetary burden estimate of either the 1970's or the 1980's. If the Milwaukee WBDO is excluded, the monetary burden in the 1990's is comparable to the estimates from the 1970's and 1980's.

5.5. MONETARY BURDEN BY WATER SOURCE TYPE

Although there were fewer WBDOs in surface water systems than in groundwater systems, the surface water system-based Milwaukee WBDO accounted for 79% of the

TABLE 5-5 Monetary Burden by Time Period, 1971 to 2000	
Decade	Monetary Burden
1971 to 1980	$41,644,000
1981 to 1990	$41,824,000
1991 to 2000	$526,912,000*
Total	$610,380,000

* Monetary Burden of Milwaukee WBDO - $461,148,000 or 87% of total monetary burden for 1991 to 2000.

total monetary burden (Table 5-6). If the Milwaukee outbreak is excluded, monetary burden attributed to groundwater systems is nearly seven times greater than the burden associated with surface water systems. Unknown and mixed water sources were negligible contributors ($45 million) to the overall burden.

Figures 5-8 and 5-9 show that the monetary burden in surface water systems is primarily associated with protozoan WBDOs. *Cryptosporidium* WBDOs dominate monetary burden associated with the surface water outbreaks (Figure 5-8). If the Milwaukee WBDO is excluded, *Giardia* outbreaks comprise 56% of the monetary burden associated with surface water systems (Figure 5-9). WBDOs attributed to bacterial agents dominate the monetary burden associated with groundwater outbreaks (Figure 5-10).

5.6. THE OVERALL MONETARY IMPACT OF THE MILWAUKEE CRYPTOSPORIDIOSIS OUTBREAK

The Milwaukee outbreak accounted for 76% of the overall monetary burden (Figure 5-11). Most of the deaths and person-days ill occurred during this WBDO as previously noted; therefore, we conducted additional analyses to explore the influence of the Milwaukee WBDO on specific aspects of the monetary disease burden estimate. We computed and compared the monetary burden with and without the Milwaukee outbreak statistics. The total burden from the Milwaukee outbreak is approximately $461 million; total burden excluding the Milwaukee outbreak is $149 million. However, the relative importance of morbidity measured by COI and mortality measured by VSL is similar whether Milwaukee is included or excluded from the analysis (Figures 5-12 and 5-13). We also examined the morbidity components of the monetary burden estimate and their effect (Figures 5-14 and 5-15). Table 5-7 summarizes the relative importance

TABLE 5-6 Monetary Burden by Water Source Type, 1971 to 2000	
Etiologic Agent	Monetary Burden
Groundwater	128,093,000
Surface Water	480,225,000*
Unknown	1,253,000
Mixed	809,000
Total	610,380,000

* Monetary Burden of Milwaukee WBDO - $461,148,000 or 87% of total monetary burden for surface water.

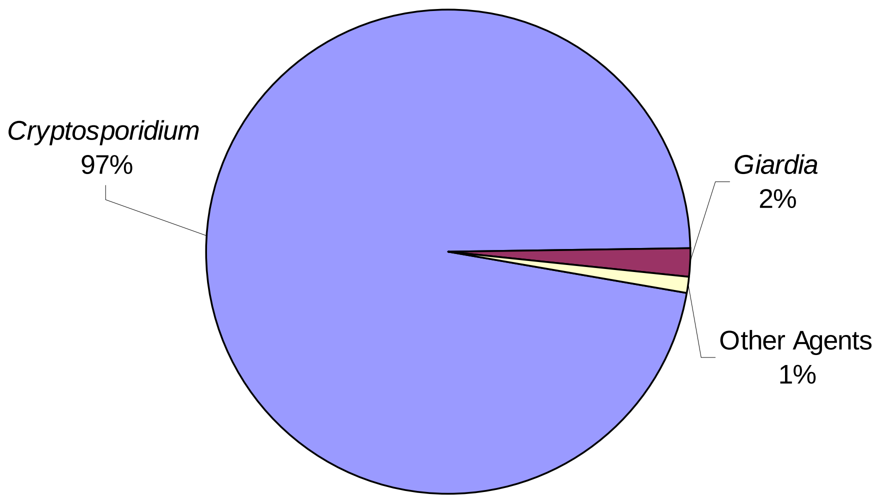

FIGURE 5-8

Distribution of Monetary Burden of WBDOs in Surface Water Systems by Etiologic Agent

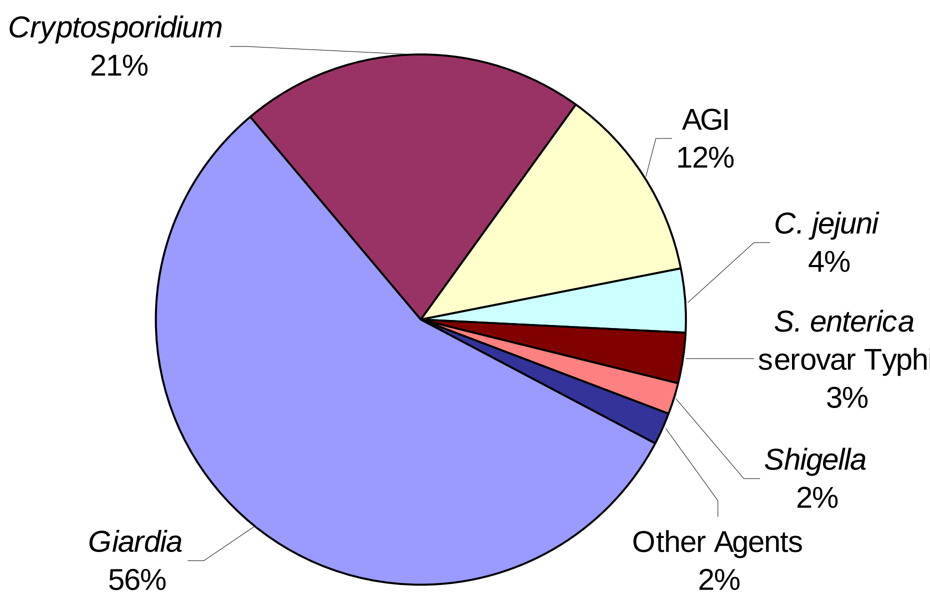

FIGURE 5-9

Distribution of Monetary Burden of WBDOs in Surface Water Systems by Etiologic Agent, Excluding the Milwaukee WBDO

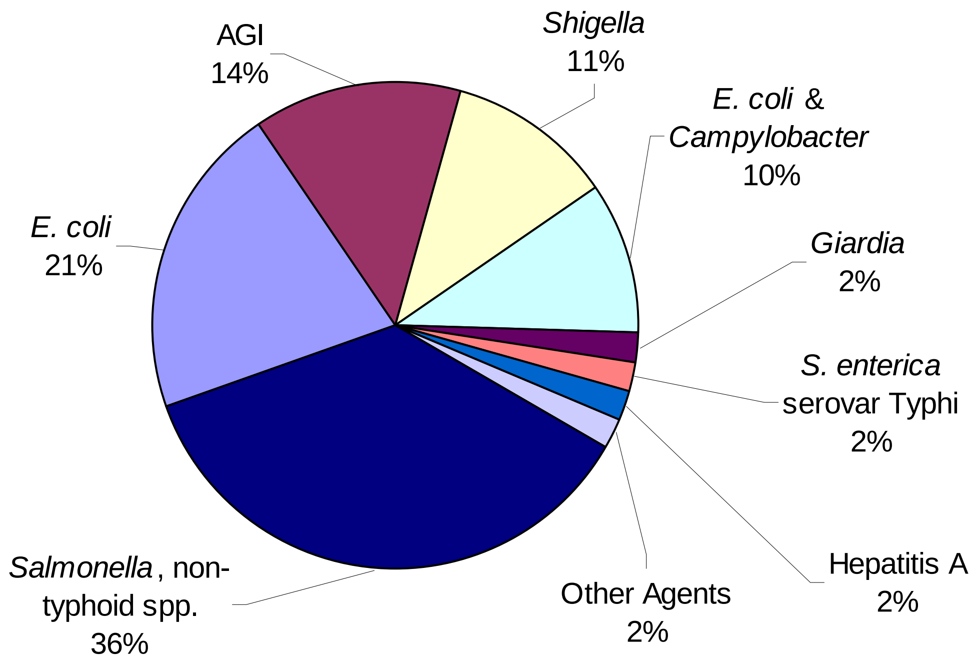

FIGURE 5-10

Distribution of Monetary Burden of WBDOs in Groundwater Systems by Etiologic Agent

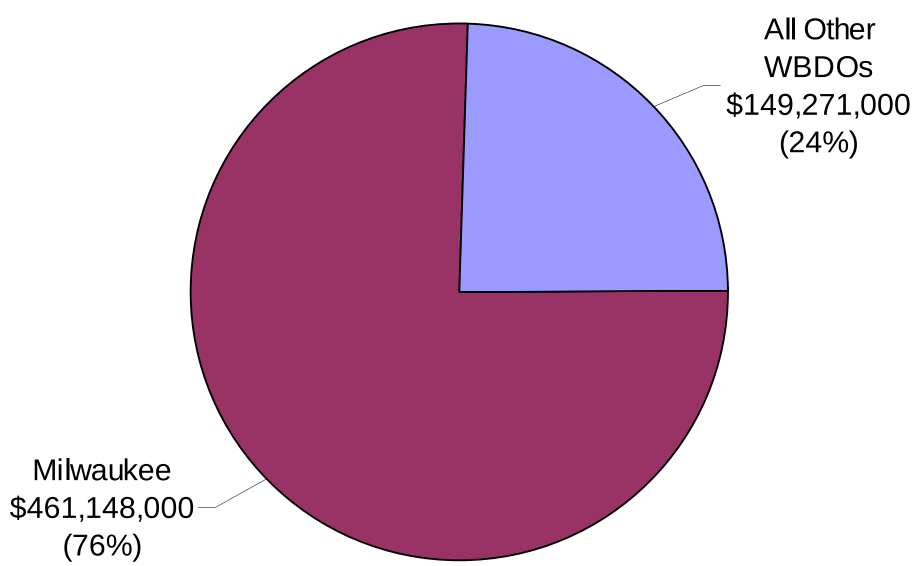

FIGURE 5-11

Contribution of the Milwaukee WBDO to the Monetary Burden Estimate from All U.S. WBDOs

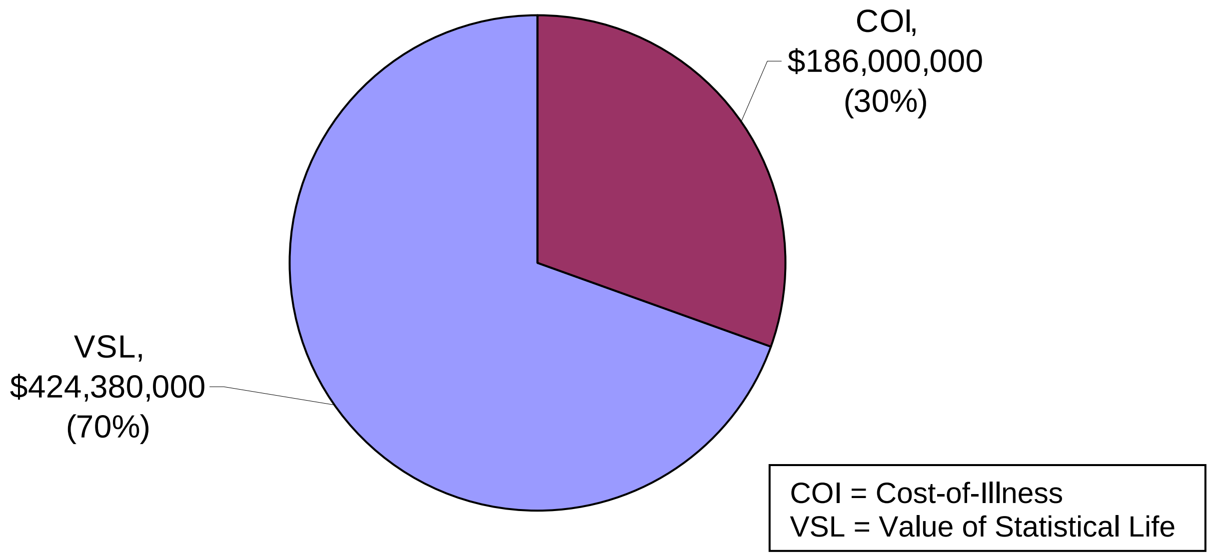

FIGURE 5-12

Component Distribution for the Monetary Burden Estimates of U.S. WBDOs

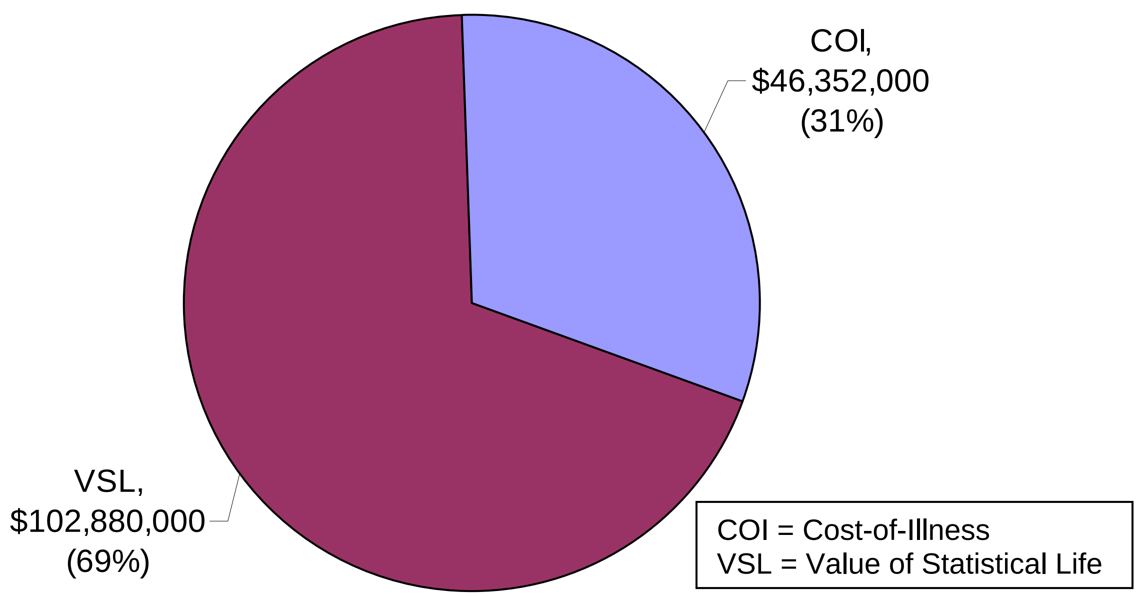

FIGURE 5-13

Component Distribution for the Monetary Burden Estimates Excluding the Milwaukee WBDO

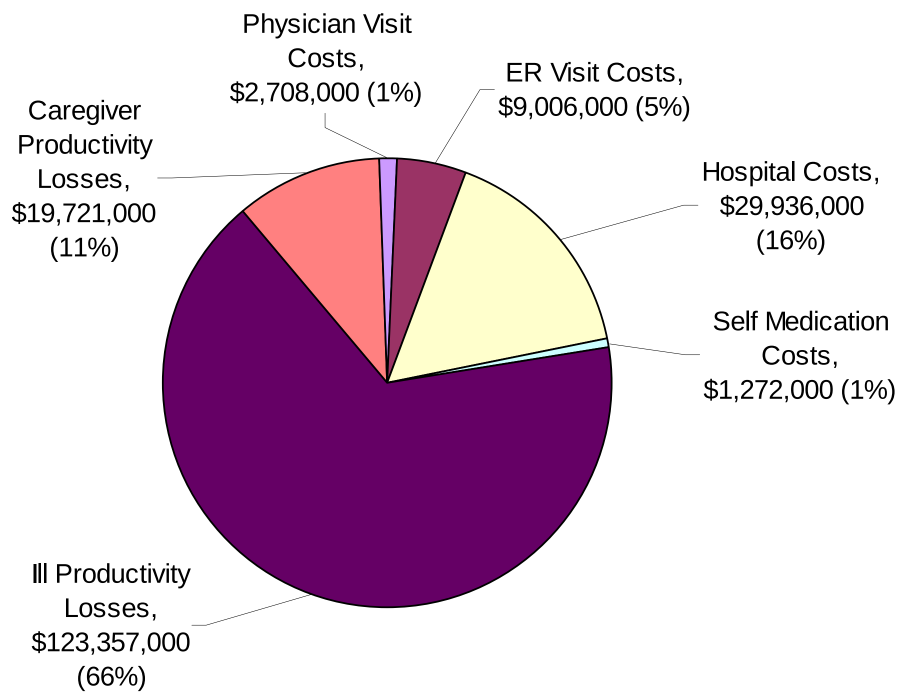

FIGURE 5-14

Cost-of-Illness Components for Monetary Burden Estimate of U.S. WBDOs

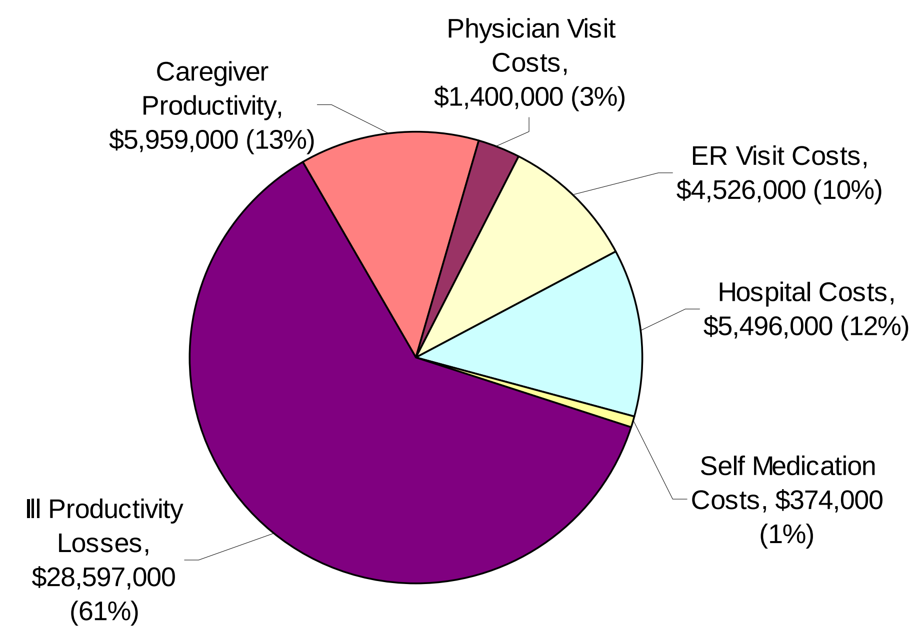

FIGURE 5-15

Cost-of-Illness Components for Monetary Burden Estimate Excluding Milwaukee WBDO

TABLE 5-7

Monetary Burden of Infectious Waterborne Outbreaks in Drinking Water, 1971 to 2000

Burden Measure	Monetary Burden	Monetary Burden Excluding Milwaukee
Self Medication	$1,272,000	$374,000
Physician Visits	$2,708,000	$1,400,000
Emergency Room Visits	$9,006,000	$4,526,000
Hospitalizations	$29,936,000	$5,496,000
Ill Productivity Losses	$123,357,000	$28,597,000
Caregiver Productivity Losses	$19,721,000	$5,959,000
Total Cost-of-Illness	$186,000,000	$46,352,000
Value of Statistical Life	$424,380,000	$102,880,000
Total	$610,380,000	$149,232,000

of the components of the monetary burden estimate. The total monetary burden based on the morbidity measures is $186 million when Milwaukee is included and $46 million when Milwaukee is excluded. The effect of the Milwaukee WBDO was to decrease the importance of the contributions of caregiver productivity losses, physician and ER visits and increase the importance of productivity losses and hospitalizations in the total morbidity monetary estimate.

5.7. DISCUSSION AND CONCLUSIONS

Monetary burden combines morbidity and mortality measures into a single metric. It allows a number of comparisons not easily accomplished with epidemiologic measures. However, the comparisons are greatly influenced by the large monetary burden associated with mortality, determined by the VSL estimate. The VSL is substantially greater than the monetary values placed on all other epidemiologic measures. WBDOs caused by pathogens that are associated with a high mortality rate will likely be identified as the most important in the monetary burden measures. The monetary values used for these morbidities associated with infection disease likely underestimate individuals' willingness-to-pay to reduce the risk of incurring the morbidity. These monetary values are based on COI approaches. As discussed in Chapter 4, such approaches likely capture a subset of disease attributes that individuals value.[1] For both of these reasons, the values used to estimate the monetary burden of the morbidity measures are low compared to the VSL.

As expected, we found that the largest burden is associated with the Milwaukee *Cryptosporidium* WBDO, in which a large number (50) of deaths were reported. The

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[1] COI approaches capture the costs from a societal perspective rather than an individual perspective, which is reflected in WTP measures.

monetary burden associated with this WBDO is evident when comparing the relative importance of the burden among various categories (i.e., community water systems, protozoan agents, *Cryptosporidium*, water treatment deficiencies, outbreaks reported from 1991 to 2000, and surface water outbreaks). A very large WBDO of cryptosporidiosis or another etiology with severe illness would also have a significant impact on the overall monetary burden and on specific categories such as water source and treatment.

6. SENSITIVITY ANALYSES FOR MONETARY BURDEN

Sensitivity analyses examine the influence of model input parameters on predictions. Allowing the values of the input parameters to vary over a range (e.g., a distribution of uncertainty in the model parameters), we can observe the relative change in model response. We conduct three such analyses to evaluate key assumptions used to develop the monetary burden estimates. In the first sensitivity analysis (Section 6.1), we identify the epidemiologic variables that have the greatest impact on the total monetary burden estimate.

In the second analysis (Section 6.2), we evaluate uncertainties associated with both the number of deaths attributed to WBDOs and their valuation. Approximately 70% ($424 million) of the total monetary burden estimate is associated with deaths. For each pathogen, we develop plausible ranges of deaths linked to WBDOs. We describe an existing distribution for the VSL and use a Monte Carlo approach to predict a plausible range of monetary burden estimates for these deaths.

The final analysis examines the impact of alternative illness durations and case estimates on the monetary burden estimated for the Milwaukee WBDO. About 76% ($461 million) of the total monetary burden estimate is associated with the Milwaukee WBDO. Although premature mortality ($322 million) accounts for 70% of the burden associated with this outbreak, the COI estimate for the Milwaukee WBDO accounts for over 75% of the total COI estimate for all WBDO.

6.1. SENSITIVITY OF THE MONETARY BURDEN TO THE EPIDEMIOLOGIC BURDEN MEASURES

Table 6-1 shows the epidemiologic burden measures reported for the WBDOs and their projected occurrence that were estimated in Chapter 2. It also shows the

TABLE 6-1 Reported and Projected Epidemiological Burden Measures for U.S. WBDOs which Occurred between 1971 and 2000			
Epidemiological Burden Measure	Reported Occurrence[a]	Projected Occurrence[b]	Additional Occurrence Estimates
Deaths[c]	66	66	0
Person-Days Ill[d]	3,992,923	4,504,854	511,931
Hospitalizations[c]	5,915	5,915	0
Emergency Room Visits	1,013	23,575	22,562
Physician Visits	21,531	41,985	20,454

[a] Reported occurrence refers to the totals actually reported in the WBDOSS. Critical data are missing for some WBDO (Chapter 2).
[b] Projected occurrence refers to the totals used in the main analysis (Chapters 2 and 3). These totals include estimates for data not reported to the WBDOSS (e.g., some outbreak reports show no estimate for duration of illness).
[c] Requested on CDC 52.12.
[d] Derived from the number of cases and illness duration which are requested on CDC 52.12.

Additional Occurrence Estimates, which are the differences between the Projected and the Reported Occurrences for each measure.

We briefly review the five projected epidemiologic measures. Because the computed rates for mortalities and for hospitalizations were comparable to the rates of occurrence reported in the literature, we assumed that this passive surveillance system does not underestimate or miss such severe events. Consequently, we did not develop approaches to adjust the estimates for hospitalizations and deaths; Table 6-1 shows the reported and projected estimates for mortalities and hospitalizations are the same.[1] Using only the WBDOs with duration estimates would underestimate the total person-days ill associated with all reported WBDOs. Therefore, we estimated durations for the remaining 42% of the WBDOs that did not report illness duration based primarily on the duration of illness caused by similar waterborne pathogens. We projected that there were approximately 4.5 million person-days ill associated with all of the WBDOs that were reported between 1971 and 2000; the projected estimate is roughly 500,000 person-days larger (13%) than if it had been based solely on the reported measures. Since emergency room visits and physician visits were not requested on the surveillance form, information for these visits was reported for few WBDOs; we projected additional occurrence of these measures, based primarily on reported rates for similar pathogens (Table 6-1).

6.1.1. Method. We estimate the change in the projected occurrence of the epidemiologic burden measure needed to cause a 5% change in the total monetary

[1] The Milwaukee WBDO accounted for 50 of the 66 deaths attributed to the U.S. WBDOs that occurred between 1971 and 2000. The study by Hoxie et al. (1997), which examined the excess mortality attributable to the Milwaukee WBDO based on the causes of death reported before, during, and after the WBDO, thoroughly analyzes this WBDO.

burden (Eq. 6-1). U.S. EPA (1997) and Breed et al. (2004) use similar approaches in a watershed delivery model and an ecosystem productivity analysis, respectively (see also discussion of approaches to sensitivity analyses in Morgan and Henrion, 1990). The quantity of the projected occurrence for each epidemiologic burden measure (Table 6-1) forms the denominator of the equation and the change in the projected occurrence forms the numerator. We note that the monetary value weights the required change in occurrence. Rearranging Eq. 6-1 to yield Eq. 6-2, we solve for the change required for each epidemiologic burden measure (converted to percentages) to change the total monetary burden estimate by 5% (Table 6-2).

$$TMB * 1.05 = \left(\frac{PO_C}{PO_I}\right) * V \qquad \text{(Eq. 6-1)}$$

where:

TMB = Total monetary burden

PO_I = Projected occurrence for given epidemiologic burden measure used in Main Study

PO_C = Projected occurrence for given epidemiologic burden measure needed to change TMB by 5%

V = Economic value of given epidemiologic burden measure

$$PO_C = \frac{TMB * 1.05 * PO_I}{V} \qquad \text{(Eq. 6-2)}$$

6.1.2. Results. Table 6-2 shows that the total monetary burden was most sensitive to differences in the number of deaths and person-days ill; a change in projected mortality by only 8% (5 deaths) changes the total monetary burden by 5%. A 21% change in the projected number of person-days ill causes a 5% change in the total monetary burden. For hospitalizations, emergency room visits, and physician visits a larger change (102%

TABLE 6-2

Percent Change Required in the Epidemiologic Burden to Change Monetary Burden Estimate for U.S. WBDOs by 5%

Epidemiological Burden Measure	Projected Occurrence	Change in the Projected Epidemiologic Burden Measure Required to Cause a 5% Change in the Total Monetary Burden	Percent Change in Epidemiologic Burden Measure Required to Cause a 5% Change in the Total Monetary Burden
Deaths	66	5	8%
Person-Days Ill	4,504,854	960,962	21%
Hospitalizations	5,915	6,031	102%
Emergency Room Visits	23,575	79,894	339%
Physician Visits	41,985	473,193	1,127%

to 1127%) in the projected measure is required to cause a 5% change in the total monetary burden. When the Milwaukee WBDO is excluded, the total monetary burden also was most sensitive to differences in the number of deaths and person-days ill (Table 6-3). For hospitalizations, emergency room visits, and physician visits a larger change (94% to 517%) in the measure is required to cause a 5% change in the total monetary burden.

6.1.3. Discussion. The sensitivity of total monetary burden to relatively small changes in the number of deaths is due to the large value associated with reducing the risk of premature death and the relatively small monetary estimates developed for the morbidities. While the VSL is based on WTP, the monetary estimates for the morbidities are based on COI approaches. As noted in Chapter 4, these monetary estimates based on COI approaches (i.e., the approach used for all of the monetary burden estimates for the morbidity endpoints) likely underestimate values developed using WTP approaches. Thus, even if relevant WTP studies were conducted, a small change in the projected number of deaths will still have a large effect on the monetary burden. Although the projections of emergency room visits and physician visits are likely the most uncertain since no comparable epidemiologic data were identified in the published literature (Chapter 2) and the projections of these measures are based upon few WBDOs, this sensitivity analysis suggests that the total monetary burden is considerably less sensitive to these two epidemiologic measures than to the deaths and person-days ill (Table 6-2).

TABLE 6-3

Sensitivity of the Monetary Burden to Changes in the Epidemiological Burden Excluding the Milwaukee Outbreak

Epidemiological Burden Measure	Projected Occurrence	Change in the Projected Epidemiologic Burden Measure Required to Cause a 5% Change in the Total Monetary Burden	Percent Change in Epidemiologic Burden Measure Required to Cause a 5% Change in the Total Monetary Burden
Deaths	16	1	6%
Person-Days Ill	877,854	227,840	26%
Hospitalizations	1,515	1,430	94%
Emergency Room Visits	11,848	18,943	160%
Physician Visits	21,705	112,193	517%

6.2. MONTE CARLO SENSITIVITY ANALYSIS OF THE MONETARY BURDEN ASSOCIATED WITH WBDO DEATHS

The monetary burden for premature death is based on a central tendency estimate for the number of premature deaths associated with WBDOs and the VSL. In this Monte Carlo analysis, we develop a plausible distribution of the monetary burden of disease associated with WBDO deaths. We use a reported distribution of the VSL from previous U.S. EPA analyses and distributions of the plausible number of deaths that could be associated with WBDOs for each pathogenic agent, as ascertained by case-fatality estimates from several literature sources. We use Monte Carlo[2] methods to predict an overall distribution of the burden estimate in monetary units. The purpose is to identify the primary sources of uncertainty in the estimate and to develop a plausible distribution of the monetary burden associated with deaths in the WBDOs.

6.2.1. Methods.

6.2.1.1. Distributions of Deaths — For each etiologic agent category (except *Cryptosporidium*), we developed distributions of the plausible number of deaths that could be expected if the lowest and highest case-fatality ratios from the literature sources discussed in Chapter 2 (Section 2.6.2) are applied to the cases reported to the WBDOSS (Table 6-4).

The 50 reported deaths in the WBDOSS that are attributed to *Cryptosporidium* in Table 6-4 are based on the death certificate analysis of Hoxie et al. (1997) that identified cryptosporidiosis as the underlying or a contributing cause of death among

[2] Monte Carlo simulation is a mathematical technique that randomly chooses a value for each variable (within a specified probability distribution) used in a model. Based on the chosen values, this technique calculates an output value. The selection and calculation steps are repeated multiple times. The outcomes are compiled forming a probability distribution for the model. This distribution is used to estimate the likelihood of a specific outcome (e.g., what is the median or 95th percentile value). Such a simulation can also be used to examine which variables have the largest influence on model output.

TABLE 6-4

Total Number of Outbreaks and Alternative Estimates of Deaths for Each Etiologic Agent

Etiological Agent (General)	Outbreaks	Cases	Low Expected Deaths	Reported Deaths (WBDOSS)	High Expected Deaths
AGI	365	83,493	0	1	33
Viruses					
Norovirus	26	13,100	0	0	0
SRSV (assumed to be norovirus)*	1	70	0	0	0
Rotavirus*	1	1,761	0	0	0
Hepatitis A	28	827	0	0	2
Bacteria					
C. jejuni	19	5,604	0	0	8
E. coli/E. coli & *Campylobacter*	12	1,529	2	6	48
*P. shigelloides**	1	60	0	0	0
Salmonella, non-typhoid spp.	15	3,203	0	7	25
S. enterica serovar Typhi	5	282	0	0	1
Shigella	44	9,196	0	2	18
V. cholerae	2	28	0	0	0
Yersinia	2	103	0	0	0
Protozoa					
Cryptosporidium	15	421,473	50	50	71
Cyclospora*	1	21	0	0	0
*En. histolytica**	1	4	0	0	0
Giardia	126	28,427	0	0	0
Total	665	569,962	52	66	206

AGI = acute gastrointestinal illness of unknown etiology
SRSV = small round structured virus
* Only a single outbreak for each etiologic agent; relatively confident in enumeration of deaths.

residents of the Milwaukee vicinity who died during the 2-year period following the Milwaukee outbreak. The analysis revealed 54 cryptosporidiosis-associated deaths that occurred during that time interval, whereas, based on pre-outbreak trends, only four would have been expected. Hoxie and colleagues also demonstrate that the total number of AIDS deaths, excluding cryptosporidiosis-associated AIDS deaths, was significantly greater than predicted during the 6 months after the outbreak (19 more deaths than expected [95% CI = 12, 26]), and that non-cryptosporidiosis-associated AIDS deaths were lower than expected during the subsequent two 6-month intervals. These changes in the pattern of AIDS deaths suggest that premature mortality among persons with AIDS could have been associated with the outbreak, and that cryptosporidiosis as a contributing cause of death may have been under-reported on their death certificates.[3] Should that have been the case, the 19 excess AIDS deaths that occurred within 6 months after the outbreak may have been cryptosporidiosis-associated, and as such, will be considered in our analysis of the distribution of plausible number of deaths. Conversely, the 50 cryptosporidiosis-associated deaths attributed to the Milwaukee WBDO may be an overestimate due to increased cryptosporidiosis awareness following the outbreak, but there are no available data to determine a possible lower bound for cryptosporidiosis mortality.

Application of the very high case-fatality ratios reported for *Cryptosporidium* in the literature sources reviewed in Chapter 2 (Section 2.6.2) yielded mortality estimates that we deemed outside the plausible range expected in the WBDOSS. Because the

[3] Hoxie et al. (1997) reported that 85% of the cryptosporidiosis-associated deaths that occurred in the Milwaukee vicinity between March 1993 and March 1995 occurred in individuals with AIDS listed as the underlying cause of death. Ideally, we would develop two case-fatality rates: one for the AIDS population and one for the general population. For this component of the upper-bound estimate, we would apply the rates separately to WBDO cases that have AIDS and the general population; however, in the absence of such data for each *Cryptosporidium* WBDO, we apply the rate to all *Cryptosporidium* WBDO cases.

vast majority of WBDO cryptosporidiosis cases are accounted for by the Milwaukee outbreak and the case-fatality ratio for these cases is thoroughly developed in the Hoxie et al. analysis, we use the Milwaukee outbreak case-fatality ratio as the basis for developing the high estimate presented in Table 6-4: total cryptosporidiosis deaths from all 15 *Cryptosporidium* WBDOs include the possible 19 additional deaths suggested by Hoxie et al. plus two more projected by applying the Milwaukee case-fatality ratio (50 deaths/403,000 cases) to the remaining 18,473 cases associated with the other *Cryptosporidium* WBDOs.[4] For each category of pathogen, triangular distributions were developed. The values for low expected deaths, reported deaths and high expected deaths correspond to the minimum, mode and maximum values of the distribution, respectively.

6.2.1.2. Distribution of Value of Statistical Life (VSL) Measures — The Economic Analysis of Long Term 2 Enhanced Surface Water Treatment Rule used a Weibull distribution for the value of a statistical life to estimate the uncertainty surrounding the VSL (U.S. EPA, 2006). This distribution included updating the previous value of the VSL to 2000$. We use their distribution which has a mean of $6.3 million,[5] median of $5.5 million, a 5th percentile value of $1.0 million and a 95th percentile value of $14.5 million. We note that the U.S. EPA and other groups are actively re-evaluating the VSL and its distribution (e.g., U.S. EPA, 2006).

6.2.2. Monte Carlo Analysis. The Monte Carlo analysis was conducted using Crystal Ball 2000 (Decisioneering, Inc., Denver, CO) and consisted of 50,000 iterations. Rank

[4] Craun et al. (2001), Craun and Frost (2002), and Hunter and Syed (2001) suggest that it is possible for the Milwaukee case estimate (Mac Kenzie et al., 1994) to be subject to recall bias. If the 403,000 cases estimated to have occurred during the Milwaukee WBDO is an overestimate, then the case-fatality rate could be higher than this rate.

[5] In the main analysis, the VSL value is $6.43 million.

correlation coefficients were calculated to analyze the impact of model parameters on the simulation results.

6.2.3. Results and Discussion: Preliminary Uncertainty Analysis of the Deaths Associated with the WBDO. Figure 6-1 shows that the number of deaths predicted ranges from 63 to 169 in this analysis. The mean of the distribution is 108 deaths and the 10th and 90th percentile values are 88 and 129 deaths, respectively.

Figure 6-2 shows the predicted mean estimate of the monetary disease burden associated with deaths attributed to WBDOs to be $684 million. The minimum and maximum values of the distribution are $3.5 million and $4.4 billion and the 10th and 90th percentile values are $167 million and $1.3 billion, respectively.

Based on our main analysis, the monetary burden associated with WBDO deaths was $424 million (Figure 5-12); the mean value in this sensitivity analysis was $260 million larger ($684 million). Figure 6-3 shows that, based on rank correlation coefficient analysis, nearly all of the model output variability can be explained through the distribution of the VSL. The distribution of the output is due primarily to the shape of the VSL distribution. It is also due to right skew of the upper-bound estimates of deaths associated with WBDOs. Comparing the reported totals (Table 6-4, column 6) to upper-bound totals shows that at the upper end of the distribution there are over 3 times more deaths than are listed in the reported data (column 5). The lower-bound values were only 23% less than the reported values, which is expected because we used the same estimate for the low and reported mortality values (n = 50).

We considered conducting an additional Monte Carlo analysis that evaluated each epidemiologic measure and each monetary measure, but doing this was not

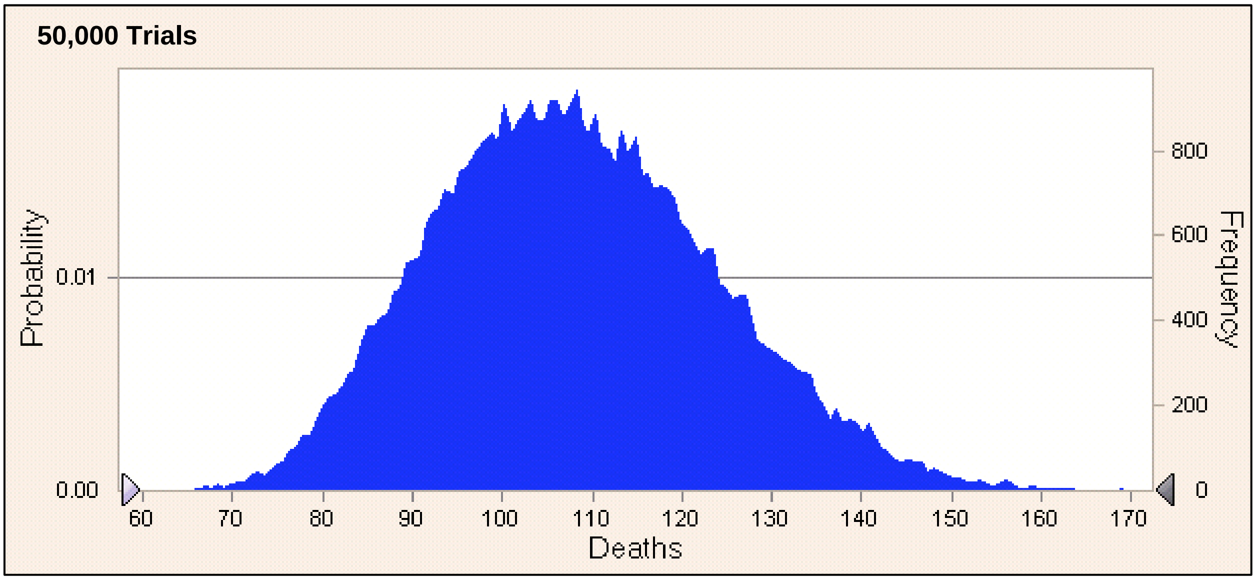

FIGURE 6-1

Predicted Distribution of U.S. WBDO Deaths Based on Monte Carlo Simulations with Distributions of the Numbers of Deaths for all Etiologic Agents

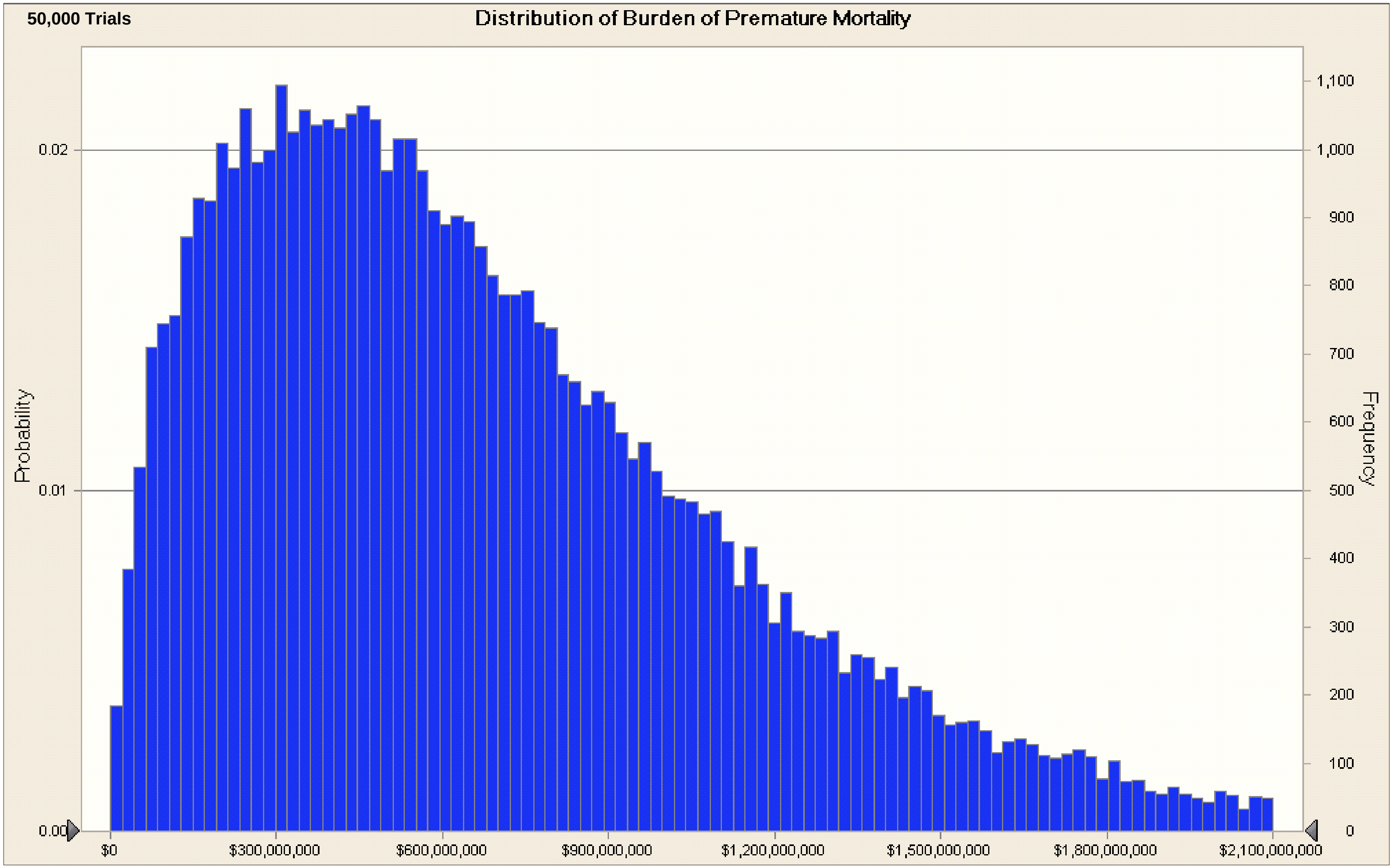

FIGURE 6-2

Predicted Distribution of Monetary Burden of U.S. WBDO Deaths Based on Monte Carlo Simulations with Distributions of the Numbers of Deaths for Each Etiologic Agent and of the VSL

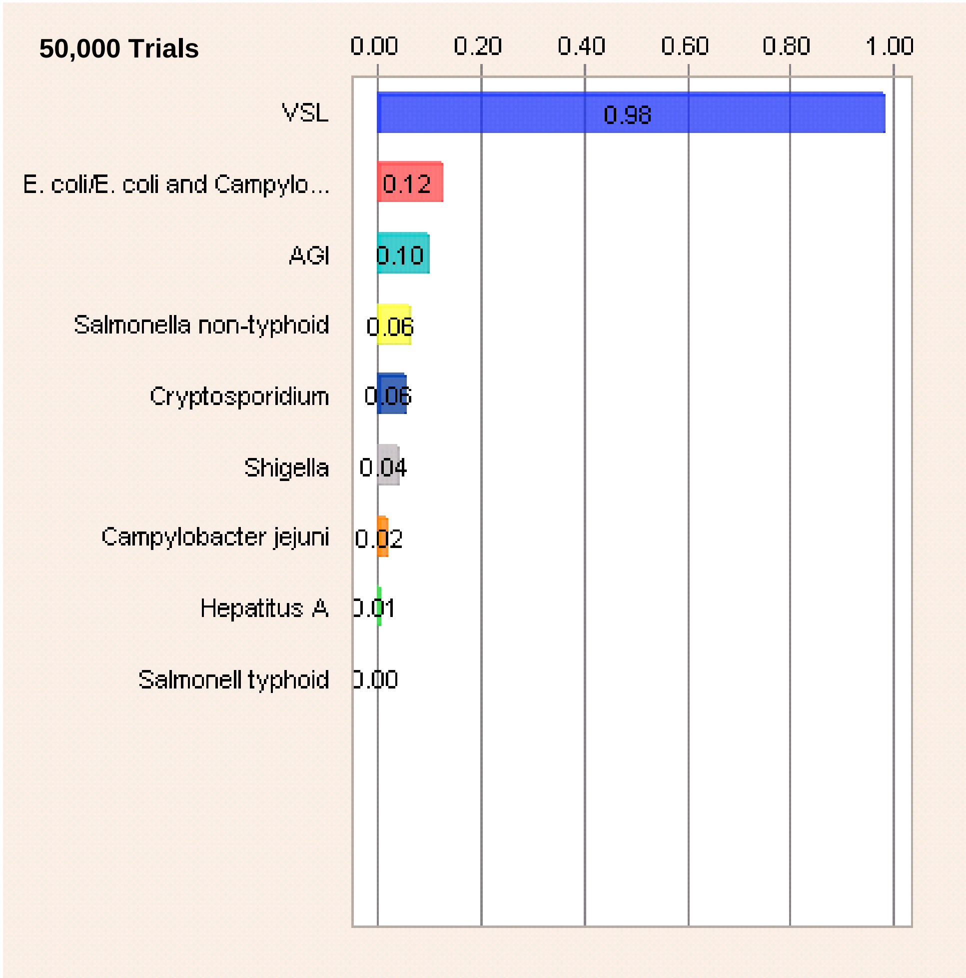

FIGURE 6-3

Rank Correlation Coefficients Associated with Mortality Sensitivity Analysis possible because we identified no studies on a national scale that systematically evaluated the uncertainty and variability in distributions of the COI measures for the morbidities associated with U.S. waterborne diseases. Although the data listed in Table 4-1 could have served as a primary source of information for the development of the COI distributions, we determined that there were insufficient data on which to develop meaningful distributions. In general, the studies described in Table 4-1 present only "central tendency" values for each COI measure as reported from different studies. While we were confident in the estimates of the central tendencies, we had little confidence in the information describing the spread of the data. If we developed an analysis based only on the distribution of these central tendency measures but did not capture appropriately the spread of these data, then the analysis would underestimate the potential impacts of the uncertainty in these data.[6] Therefore, we limited our analysis to uncertainty in the monetary burden associated with WBDO deaths.

6.3. SENSITIVITY ANALYSIS OF THE MONETARY BURDEN ASSOCIATED WITH THE MILWAUKEE OUTBREAK TO THE REPORTED DURATION OF ILLNESS AND CASE NUMBER

This sensitivity analysis examines the impact of changes in two epidemiologic burden components, case number and illness duration, on the monetary burden estimate. Although not as influential as changes in the number of deaths (Section 6.1), these two components account for much of the monetary burden associated with the 659 WBDOs which report no fatalities (i.e., no deaths are associated with over 99% of 665 total WBDOs reported in the WBDOSS between 1971 and 2000). Both the duration of illness and the number of cases of illness are needed to compute the person-days ill, which is then used to estimate the monetary burden associated with lost productivity.

[6] A comprehensive uncertainty analysis, while outside the scope of this effort, is clearly needed.

Chapter 6 shows that these two components require a magnitude change of 21-25% to change the total monetary burden estimate by 5%.

To illustrate the impact on monetary burden, we develop several estimates of both the number of cases of illness that occurred during the Milwaukee WBDO and their average duration. We then examine the influence of these alternative estimates on the associated monetary disease burden estimated for this WBDO. The Milwaukee WBDO is well studied, making it a convenient source of published estimates for this illustrative analysis. Although most of the monetary burden is associated with the 50 deaths attributed to the the Milwaukee outbreak, in the main analyses this WBDO contributes significantly to the number of person-days ill and monetary burden due to the large number of estimated cases (403,000) and illness duration (i.e., 9 days) (Chapters 3 and 5). We did not examine alternative estimates of the number of premature mortalities because of the large impact of small changes on monetary burden (Sections 6.1 and 6.2) and the focus of this section. Most of the case number and duration estimates reported for the other WBDOs are subject to the same uncertainties described in subsequent sections for the Milwaukee WBDO (e.g., recall bias, uncertain background illness rates) and, as noted in Chapter 2, the methods we used to estimate the unreported measures are also uncertain.

6.3.1. Alternative Estimates of Duration of Cryptosporidiosis During Milwaukee WBDO. Although Mac Kenzie et al. (1994) report only a median illness duration of 9 days in the abstract of their published article, they surveyed three populations with different mean and median illness durations: (1) persons with laboratory confirmed cryptosporidiosis, (2) persons with clinically-defined cryptosporidiosis (i.e., symptoms consistent with cryptosporidiosis) and (3) a household survey of persons with watery diarrhea (the case-definition used to identify cryptosporidiosis in Mac Kenzie et al.). The reported duration of illness among these populations ranged from 1 to 55 days (Table 6-5). Median values of 3 days duration for watery diarrhea were reported in the clinical infection and household surveys, which contrast sharply with the median duration of 9 days for laboratory-confirmed cases. Of the 285 laboratory-confirmed patients 46% were hospitalized and 48% were immuno-compromised, and these cases may have been among the most severe and long lasting. For our main epidemiologic and monetary burden analyses, we used the reported median duration of illness of 9 days. Nine days is the typical duration of illness reported in the CDC fact sheets for cryptosporidiosis and is also the midpoint of the median durations listed for all 12 *Cryptosporidium* WBDOs (Table 6-6). In these WBDOs, the median duration reported during a *Cryptosporidium* WBDO ranged from 3 to 74 days. For this sensitivity analysis, we assumed that the average duration of cryptosporidiosis in the Milwaukee WBDO was alternatively 3 or 9 days.

6.3.2. Alternative Estimates of Milwaukee Cryptosporidiosis Cases. The WBDOSS attributes 403,000 cases of cryptosporidiosis to the Milwaukee outbreak. This is the central estimate of the number of cases estimated by Mac Kenzie et al. (1994) in their outbreak investigation (details provided in Chapter 2). They estimated the number of people that had symptoms consistent with cryptosporidiosis during the outbreak by means of a telephone survey in which 26% of the respondents reported watery diarrhea during the period of the outbreak (defined as March 1-April 28, 1993). By applying the proportion of persons experiencing the symptom compatible with

TABLE 6-5

Duration of Illness, Milwaukee *Cryptosporidium* Outbreak (Mac Kenzie et al., 1994)

Population Surveyed	Duration (Days)			Survey Information
	Median	Mean	Range	
Laboratory-Confirmed Cases	9	12	1 to 55	n = 285 lab confirmed cases
Clinical Infection	3	4.5	1 to 38	n = 201 respondents with watery diarrhea (482 total respondents)
Household Survey	3	-	1 to 45	n = 436 interviewed with watery diarrhea (1663 total household members)

TABLE 6-6

Distribution of Reported Median Duration of Illness of *Cryptosporidium* WBDOs, 1971 to 2000

Median Reported Duration of Illness	Number of WBDOs Reporting Median Duration Value
3.0	1
4.0	1
5.0	1
6.0	1
7.0	1
8.6	1
9.0*	1*
11.0	2
24.0	1
60.0	1
74.0	1

* Milwaukee WBDO

cryptosporidiosis to the total population at risk (1.61 million people), they estimated that 419,000 persons (95% confidence interval = 386,000-451,000) may have been ill during the Milwaukee WBDO (Table 6-7). After subtracting a background rate of 0.5% per month for diarrhea due to all causes (16,000 people/2-month outbreak period), it was determined that 403,000 people experienced watery diarrhea due to the cryptosporidiosis outbreak.

To develop a high-end case number estimate for burden analysis, we subtract the background cases from the value of the upper 95% confidence interval and project 435,000 cases. Although not used here, other approaches could be considered for development of a high-end estimate. For example, a study of *Cryptosporidium*-specific antibody responses in children by McDonald et al. (2001) suggests that infection may have been more widespread,[7] and Naumova et al. (2003) also emphasize the importance of secondary transmission especially among children and the elderly, which could have led to additional unreported cases. The estimated 403,000 cases include only the symptomatic cases that occurred between March 1 and April 28, 1993. Given the 2-month duration of the study, we assume that this estimate consists of primary and secondary cases; however, secondary cases that occurred after this survey time period would not be included in the case estimate of Mac Kenzie et al. (1994). This estimate also would not include asymptomatic cases; while such cases could contribute to secondary spread in the population, they would not contribute to either the epidemiologic or monetary burden estimates since they would not be described by the epidemiologic measures used in our analysis.

[7] We note that infection does not imply that the individual was ill.

TABLE 6-7 Alternative Estimates of Number of Cases Attributable to the Milwaukee WBDO			
Source of Background Incidence Estimate	Background Incidence (Episodes [cases] per person per year)	Background Rate (% of Milwaukee area residents[a] experiencing background [i.e., non-outbreak-related] cases of diarrhea per month)	Cases of Diarrheal Illness (computed from Mac Kenzie's survey-based estimate of 419,000 [95% CI, 386,000-451,000] cases of watery diarrhea)
Mac Kenzie et al. (1994) Upper 95% CI	0.06[b]	0.5%[b]	435,000
WBDOSS	0.06[b]	0.5%[b]	403,000
Mac Kenzie et al. (1994) Lower 95% CI	0.06[b]	0.5%[b]	370,000
Mead et al. (1999)	0.61[c]	5.1%[c]	255,317
Roy et al. (in press)	0.65[d]	5.4%[d]	244,583
Hunter and Syed (2001)	1.404[e]	11.7%[e]	42,260

[a] greater Milwaukee area population of 1,610,000
[b] restricted to cases of "watery diarrhea"
[c] mean of age-adjusted incidence of episodes or cases of "any diarrhea, with or without vomiting" presented in Mead et al. as derived from 1996/97 FoodNet data (CDC, 1998b), the Cleveland study (Dingle et al., 1964), and the Tecumseh study (Monto and Koopman, 1980)
[d] episodes or cases of AGI defined as "3 or more loose stools in a 24-hour period resulting in an impairment of daily activities or diarrhea duration greater than one day"
[e] episodes or cases of AGI of any symptom profile ascertained from FoodNet 1997 data (CDC, 1998c)

To develop a low-end estimate, we subtract the background rate used by Mac Kenzie et al. (16,000) from their lower-bound 95% confidence interval (386,000) and estimate that the outbreak consisted of 370,000 cases. Although not used for this burden analysis of WBDOSS reported cases, several other evidentiary lines could be considered for development of alternative low-end estimates of the number of Milwaukee cases. To estimate the number of cases that occurred during a WBDO, epidemiologic investigations rely on subjects' recollection of experiencing specific symptoms during a specific period of time and the identification of an appropriate background illness rate to compare with the increased disease incidence. Even though the 1993 Milwaukee cryptosporidiosis outbreak investigation (Mac Kenzie et al., 1994; Hoxie et al., 1997; Proctor et al., 1998) was quite extensive, Hunter and Syed (2001) suggest that outbreak-related cases may have been overestimated due to recall bias and the use of a background incidence rate that was too low.

The background rate assumed in the Mac Kenzie study was 0.5% per month (or 16,000 cases during the 2-month period per 1,610,000 people in greater Milwaukee – the equivalent of an annual diarrheal risk of about 0.06 cases per person per year); the source was cited as "unpublished data." Roy et al. (in press) estimate general background incidence rates of AGI in the United States to be 0.65 episodes per person-year (this would indicate 174,417 background AGI cases during the 2-month Milwaukee WBDO, a 5.0% per month rate). The Roy et al. background incidence rate for AGI is comparable to that that we computed (0.61 episodes per person-year) for AGI characterized by diarrhea of any type (with or without vomiting) based on the rates provided in Table 4 of Mead et al. (1999). Mead et al. evaluated retrospective community-based studies in the United States (Dingle et al., 1964 [the Cleveland study]; Monto and Koopman, 1980 [the Tecumseh study]) and 1996/97 FoodNet data, and developed age-adjusted rates of AGI with several symptom profiles. Age-adjustment was conducted because the Cleveland and Tecumseh studies over-sample children. By considering the age-adjusted incidence of diarrheal illness provided by Mead et al., we compute an average background diarrhea incidence of rate of 0.61 cases per person-year (5.0% per month;[8] 163,682 cases per 1,610,000 people per 2-month period). Hunter and Syed, in considering the same data sets as Mead et al., suggest a background incidence rate of 11.7% per month,[9] or 376,740 cases per 1,610,000 per 2-month period – the equivalent of an annual diarrheal illness incidence of about 1.4 cases per person per year (presumably for all AGI symptom profiles and without age-adjustment). If such a background rate was representative of Milwaukee at that time, the outbreak cryptosporidiosis cases would number only 42,260 after accounting for the higher background rate of diarrheal illness. Alternative estimates are summarized in Table 6-7.

Furthermore, recall bias may result in the reporting of more illnesses than actually occurred (Craun and Frost, 2002; Craun et al., 2001; Hunter and Syed, 2001). These researchers reason that the Mac Kenzie et al. estimate could be subject to recall bias, given the increased publicity and the primary investigators' reliance on self-reporting of non-specific diarrheal illness. Hunter and Syed point out that, according to

[8] An incidence rate of 0.61 cases per person-year/12 = 0.051 cases per person-month, i.e., a background rate of 5.0% per month.
[9] An incidence rate of 1.4 cases per person-year/12 = 0.117 cases per person-month, i.e., a background rate of 11.% per month.

TABLE 6-8

The Alternative Estimated Numbers of Cases and Epidemiologic Burdens of the Milwaukee WBDO
9 Days Median Duration of Illness

Alternative	Cases	Physician Visits	Emergency Room Visits	Hospitalizations	Deaths	Person-Days Ill	Number Cases Self Medicating	Ill Productivity Days Lost	Caregiver Productivity Days Lost
I9	435,000	21,890	12,658	4,749	50	3,915,000	130,453	710,308	103,157
II9	403,000	20,280	11,727	4,400	50	3,627,000	120,856	658,055	95,568
III9	370,000	18,620	10,770	4,040	50	3,330,000	110,960	604,170	87,740

I9 = case number reported for upper bound of 95 percentile confidence interval in Mac Kenzie et al. and 9-day duration.
II9 = case number as reported in waterborne outbreak database and 9-day duration.
III9 = case number reported for lower bound of 95 percentile confidence interval in Mac Kenzie et al. and 9-day duration.

TABLE 6-9

The Alternative Estimated Numbers of Cases and Epidemiologic Burdens of the Milwaukee WBDO
3 Days Median Duration of Illness

Alternative	Cases	Physician Visits	Emergency Room Visits	Hospitalizations	Deaths	Person-Days Ill	Number Cases Self Medicating	Ill Productivity Days Lost	Caregiver Productivity Days Lost
I3	435,000	21,890	12,658	4,749	50	1,305,000	130,452	236,769	34,385
II3	403,000	20,280	11,727	4,400	50	1,209,000	120,856	219,352	31,856
III3	370,000	18,619	10,767	4,040	50	1,110,000	110,960	201,390	29,247

I3 = case number reported for upper bound of 95 percentile confidence interval in Mac Kenzie et al. and 3-day duration.
II3 = case number as reported in waterborne outbreak database and 3-day duration.
III3 = case number reported for lower bound of 95 percentile confidence interval in Mac Kenzie et al. and 3-day duration.

Wheeler et al. (1999), in comparison to prospective studies, retrospective studies overestimate diarrheal illness in a community by a factor of 2.8.

6.3.3. Effect of Alternative Case Numbers and Duration of Illness on the Burden of the Milwaukee WBDO. Tables 6-8 and 6-9 present the conjectured epidemiologic burden possibilities under six alternative combinations of case number and duration-of-illness estimates for the Milwaukee outbreak: three different case number estimates evaluated at 3 and 9 days duration of illness. Because this analysis focuses on alternative case and illness duration estimates, the number of deaths attributed to this WBDO was not changed in any of the alternatives. The number of physician visits, emergency room visits, hospitalizations and number of cases that self-medicated are affected by changes in conjectured case number (i.e., 435,000 vs. 403,000 vs. 370,000). As the number of cases declines in the conjectured estimates, there will be a proportional decrease in these estimates. Person-days ill varies with both case number and duration of illness. For example, the number of person-days ill reported in Table 6-8 (median duration of illness is assumed to be 9 days) is three times greater than the corresponding number of person-days ill listed in Table 6-9 (median duration of illness is assumed to be 3 days).

Tables 6-10 and 6-11 show that the COI associated with these conjectured estimates for the Milwaukee outbreak could range from approximately $61 million to $151 million. The total monetary burden could range from $383 million to $472 million; thus, most (approximately $322 million) of the monetary burden is associated with the 50 deaths attributed to this outbreak. The COI estimated for the median duration of three days is roughly one-half the value estimated for nine days (Figure 6-4). Tables

TABLE 6-10

Results of Conjectured Alternative Numbers of Cases and Economic Burdens of the Milwaukee WBDO
9 Days Median Duration of Illness

Alternative	Physician Visit Cost ($)	ER Visit Costs ($)	Hospital Costs ($)	Self Medication Costs ($)	Cost of Ill Productivity Losses ($)	Cost of Caregiver Productivity Losses ($)	Cost of Illness Total ($)	Estimated Burden of Death ($)	Total Monetary Burden ($)
I9	1,411,926	4,835,800	26,380,144	969,872	102,284,317	14,854,535	150,736,594	321,500,000	472,236,594
II9	1,308,060	4,480,063	24,439,536	898,525	94,759,953	13,761,787	139,647,925	321,500,000	461,147,925
III9	1,200,948	4,113,209	22,438,284	824,949	87,000,453	12,634,891	128,212,735	321,500,000	449,712,735

I9 = case number reported for upper bound of 95 percentile confidence interval in Mac Kenzie et al. and 9-day duration.
II9 = case number as reported in waterborne outbreak database and 9-day duration.
III9 = case number reported for lower bound of 95 percentile confidence interval in Mac Kenzie et al. and 9-day duration.
$ = all dollar estimates in 2000$

TABLE 6-11

Results of Conjectured Alternative Numbers of Cases and Economic Burdens of the Milwaukee WBDO
3 Days Median Duration of Illness

Alternative	Physician Visit Cost ($)	ER Visit Costs ($)	Hospital Costs ($)	Self Medication Costs ($)	Cost of Ill Productivity Losses ($)	Cost of Caregiver Productivity Losses ($)	Cost of Illness Total ($)	Estimated Burden of Death ($)	Total Monetary Burden ($)
I3	1,411,926	4,835,800	26,380,144	969,872	34,094,772	4,951,512	72,644,026	321,500,000	394,144,026
II3	1,308,060	4,480,063	24,439,536	898,525	31,586,651	4,587,262	67,300,098	321,500,000	388,800,098
III3	1,200,948	4,113,209	22,438,284	824,949	29,000,151	4,211,630	61,789,172	321,500,000	383,289,172

I3 = case number reported for upper bound of 95 percentile confidence interval in Mac Kenzie et al. and 3-day duration.
II3 = case number as reported in waterborne outbreak database and 3-day duration.
III3 = case number reported for lower bound of 95 percentile confidence interval in Mac Kenzie et al. and 3-day duration.
$ = all dollar estimates in 2000$

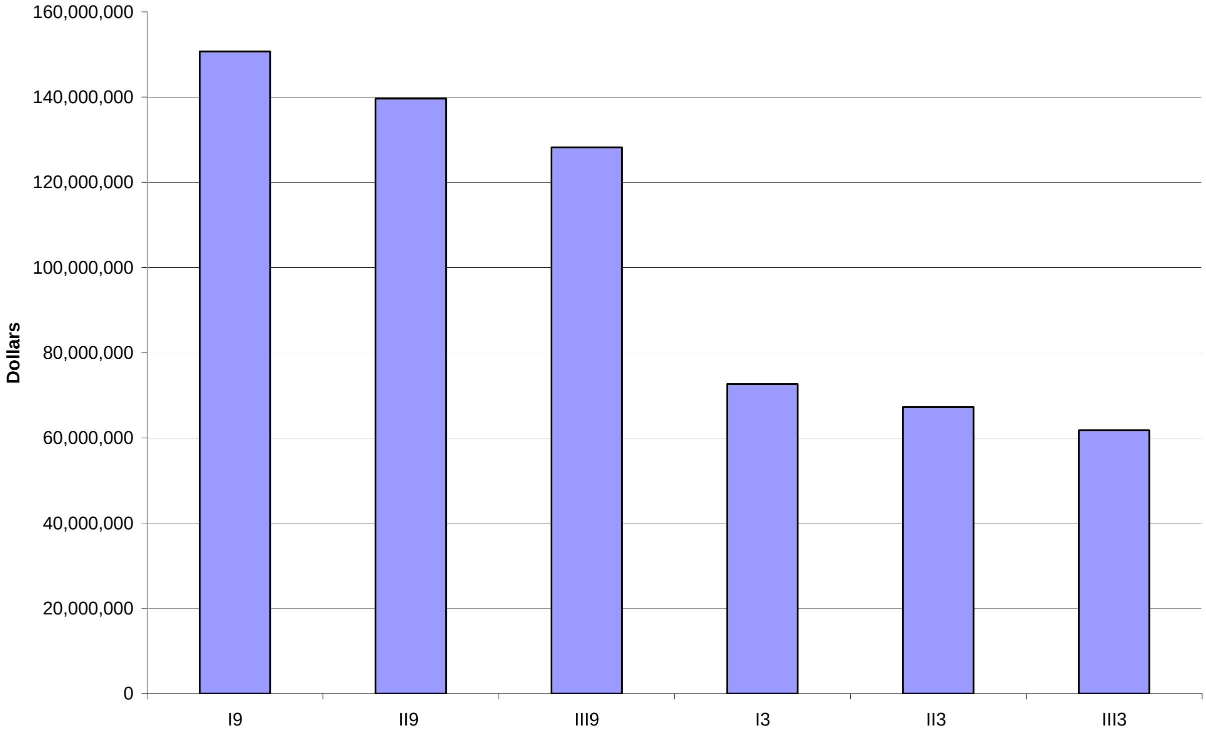

FIGURE 6-4

COI Estimates Associated with Alternative Impacts of the Milwaukee WBDO

6-10 and 6-11, which list the results of each economic measure for each alternative outbreak, show that lost productivity of both the ill person and the caregiver account for most of the differences across the alternative COI estimates. For example, assuming that there were 403,000 cases resulting from the Milwaukee WBDO, the lost productivity for the ill is valued at $95 million if duration of illness is 9 days but only $32 million if it is 3 days.

6.4. CONCLUSIONS OF SENSITIVITY ANALYSIS

This chapter describes three separate examinations of the uncertainty associated with the monetary burden estimate. The first analysis demonstrates how changes in the various epidemiologic measures (e.g., total hospitalizations, total person-days ill) would alter the total monetary burden estimate. Relatively small changes in the number of deaths and person-days ill will bring about a 5% difference in the total burden, illustrating that deaths, case numbers and duration of illness are the most influential factors in these burden estimates. In contrast, the overall magnitude of the medical treatment components (i.e., numbers of hospitalizations, physician visits and emergency room visits) would have to be markedly different from the estimated values to affect the total burden to a significant degree. These results suggest that uncertainty in the numbers of deaths and cases and in the duration of illness is of much greater concern than the uncertainty in the medical treatment factors.

The second and third analyses were conducted because the information needed to develop a comprehensive uncertainty analysis was not available. As noted previously, while we are confident in the central tendency measures, we were unable to develop distributions that we deemed adequate for this analysis. The development and publication of data sets for the costs associated with the various morbidities that result from a WBDO is a clear research need. Also needed are valid methods used to quantify plausible distributions of the illness durations, physician visits, emergency room visits and hospitalizations associated with WBDOs. Because we could not conduct a comprehensive uncertainty analysis, we focused the following two analyses on the two components of the WBDO surveillance system that had the greatest impact on the total monetary burden: the total number of deaths attributable to WBDOs and the 1993 Milwaukee cryptosporidiosis outbreak. Chapters 4 and 5 document these impacts. Deaths and the Milwaukee outbreak account for roughly 70% and 76% of the monetary disease burden, respectively (consider that 50 deaths were reported for the Milwaukee WBDO alone and only 16 deaths occurred in the remaining 665 WBDOs).

In the second analysis, we developed a distribution of the number of deaths associated with each pathogenic agent and for AGI and used a distribution for the VSL. This analysis showed that the distribution of the VSL was the most important contributor to the monetary disease burden associated with premature mortalities. The distribution of deaths associated with each agent was relatively small when compared to the distribution used to represent the VSL.

The third analysis focused on the impact of alternative case and duration estimates during the 1993 Milwaukee cryptosporidiosis outbreak, which was responsible for the majority of the burden in all of the burden estimates. The analysis showed that, if a 3-day average duration of illness was used instead of a 9-day duration, then the monetary burden would decrease by approximately one-half. For the 9-day duration, decreasing case estimates by 8% resulted in total monetary burden estimates that were

2.5% lower than those based on the reported values. The same case reductions for the 3-day duration showed 1.6% lower monetary burden estimates for the Milwaukee WBDO. This further highlights the importance of the contribution of the total number of deaths that occurred during the outbreak.

7. DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

We examined the epidemiologic and monetary burden from WBDOs reported in the U.S. from 1971 to 2000. Monetary burden estimates were based on epidemiologic measures recorded in the WBDOSS including the number of cases of illness, illness duration, hospital admissions, physician visits, emergency room visits and deaths. We estimated unreported severity measures such as illness duration and the number of physician and emergency room visits based on data available from published literature or, preferably, from other outbreak data in the WBDOSS. We also examined the sensitivity of the total disease burden estimate to various assumptions (e.g., illness duration in the Milwaukee outbreak, the magnitude of the value of statistical life (VSL)) in order to address some of the uncertainty in the results.

7.1. DISCUSSION

The total estimated monetary burden from the 665 outbreaks reported in the 30-year WBDOSS was $610 million. This was based on 66 deaths, approximately 570,000 cases of illness and over 4.5 million person-days ill. The VSL analysis, which estimates the monetary burden from premature mortality, accounted for $424 million of the total burden. The COI analysis, which estimates costs related to morbidity including medical expenses and productivity loss (i.e., days lost for work valued by lost wages and household production for the sick individual and their caregivers), accounted for the remaining $186 million. Similar to the Corso et al. (2003) analysis of the Milwaukee cryptosporidiosis outbreak, productivity losses accounted for the majority of the COI disease burden estimate for WBDOs during 1971-2000. The proportion of the COI burden due to productivity losses in our analysis was 77%.

The number of cases ill and the duration of illness were used to calculate person-days ill attributable to WBDOs. The majority of WBDO cases and estimated person-days ill occurred in surface water systems. This was mostly due to the Milwaukee cryptosporidiosis outbreak, which contributed 403,000 of the 570,000 cases recorded from 1971 to 2000. Given the magnitude of the Milwaukee outbreak and its impact on the overall disease burden, we examined the epidemiologic burden associated with and without the Milwaukee outbreak. Without the Milwaukee outbreak cases, the reported number of cases of illness in groundwater systems was twice as high as the number in surface water systems while person-days ill estimates were slightly higher in surface water systems.

Community systems serve over 272 million persons in the U.S., of which 181 million are served by surface water (U.S. EPA, 2005). Groundwater serves over 111 million people in the U.S. and is the primary source for most non-community water systems. Although they serve fewer than 25 million people in the U.S., non-community systems accounted for the majority (n = 329) of the reported WBDOs. In spite of the greater frequency of WBDOs in non-community systems, most of the epidemiologic burden occurred in community water systems irrespective of whether Milwaukee was considered. After excluding Milwaukee, reported cases in non-community and community system outbreaks were fairly comparable, but the person-days ill estimate remained more than twice as high in community systems. This is likely due in part to longer average duration of protozoan infections, which largely occur in surface water-supplied community water systems. In contrast, the shorter duration of illness reported for outbreaks from non-community systems is consistent with a viral etiology more commonly found in groundwater outbreaks (Borchardt et al., 2003). Overall, the total monetary burden associated with community outbreaks was 13 times larger than non-community systems with the Milwaukee outbreak included and 2.5 times larger without Milwaukee.

Among the 300 outbreaks of known etiology, 143 were attributed to protozoa, 101 to bacteria and 56 to viruses. After excluding Milwaukee, protozoan outbreaks accounted for nearly 47,000 cases of illness. This was more than two times and more than three times the reported cases from bacterial and viral outbreaks, respectively. The person-days ill estimate for protozoan outbreaks was 463,000, more than 3 times higher than the combined estimate for both viral and bacterial outbreaks. The 365 AGI outbreaks accounted for over 83,000 reported cases of illness and an estimated 265,000 person-days ill.

The ability for passive WBDO surveillance systems to accurately estimate the different epidemiologic measures is critical for the burden estimates that were developed. This is not only important at the individual outbreak level, but incomplete reporting of epidemiologic data could distort some of the comparisons that were made by etiologic agent grouping. For example, only one rotavirus outbreak was reported to the WBDOSS during the 30-year period. Since rotavirus was the only viral outbreak other than Hepatitis A with reported physician visits, the rotavirus data was used to estimate physician visits for other viruses such as norovirus and small, round structured viruses (assumed to be norovirus). If the epidemiologic measures for the rotavirus outbreak are inaccurate or not representative of typical outbreaks, the impact of these errors would be compounded by their use in estimating measures for other viral outbreaks. Since data limitations resulted in the estimation of unreported measures based on other outbreaks with similar etiology (or etiologic group), we urge caution in the interpretation of the findings based on limited data.

The disease burden estimates presented in this report are dependent on the extent to which outbreaks were investigated, detected, reported and recorded in the WBDOSS. The likelihood that an outbreak is detected and recorded is dependent on local and state disease surveillance capabilities as well as a variety of factors including water service system and source water type. For small non-community water systems that serve part-time or transient populations and non-residential areas, there is an increased likelihood for outbreaks to go undetected due to insufficient clustering of cases (Lee et al., 2002). Outbreaks may also go undetected in larger communities due to factors such as decentralized health care systems and numerous, non-integrated laboratory facilities (Board on Life Sciences, 2004). Outbreaks that result in mild symptoms, have low attack rates or are not caused by an easily identifiable etiologic agent are also more likely to go unrecognized. Because we do not consider unreported outbreaks that may have occurred during 1971-2000 when estimating disease burden, they likely are underestimates of the actual burden attributable to all possible WBDOs.

In our burden analyses, we did not attempt to identify likely etiologic agents for outbreaks categorized as AGI; however, we did examine the frequency of AGI outbreak by water system type. Since most of the AGI outbreaks occurred in groundwater systems, a viral origin is suspected for most of these outbreaks (Barwick et al., 2000; Lee et al., 2002). Recent advances in molecular methods have increased the likelihood that viruses will be detected, but linking WBDOs to viruses remains a challenge since clinical specimens and water samples are still not routinely examined for viruses (Blackburn et al., 2004; Yoder et al., 2004). We, therefore, expect considerable uncertainty in the disease burden estimates for viruses due to the likelihood that many of the AGI outbreaks are of viral etiology and the possibility that viral illnesses are less effectively captured by surveillance systems than protozoan or bacterial illness cases (Wheeler et al., 1999).

The ability of the passive WBDOSS to capture the true magnitude of the WBDO disease burden in the U.S. is limited given the presumed under-reporting of outbreaks and variability in thoroughness and rigor in reporting of epidemiologic data for different outbreaks. Case number reports for outbreaks are dependent on the capacity of local public health agencies and laboratories to identify cases and link these in a timely manner to a common source of exposure to an etiologic agent. Case enumeration is also impacted by the nature of the illness occurring during an outbreak. Since waterborne infectious disease often manifests as gastroenteritis or another self-limiting illness with mild symptoms, only a small proportion of cases may seek medical attention, thereby limiting the number of ill persons that are reported to a disease surveillance system. For example, the FoodNet survey of 14,647 U.S. residents conducted during 2000-2001 indicated that 5% of those surveyed reported acute diarrheal illness during the previous 4 weeks (Imhoff et al., 2004). Only 23% of those who were ill visited a health care provider, and 17% of those seeking medical care reported submitting a stool specimen for culture. This indicates that only 4% of those who were ill were asked to submit a stool sample, greatly limiting the likelihood of identifying an etiologic agent for most cases for acute gastrointestinal illnesses.

Although mild cases of disease may frequently go unreported, they could represent a large portion of the disease burden from WBDOs. Mild cases accounted for nearly 43% of the total disease burden (based on COI analyses) from the Milwaukee outbreak. This may not be representative of other outbreaks that are less thoroughly investigated, since an estimated 88% of the mild cases did not seek medical care (Corso et al., 2003). Garthright et al. (1988) estimated the total costs from medical expenses and lost productivity associated with mild gastrointestinal illness in the U.S. during 1985 at $44.9 billion for cases with no physician consultation, $6.3 billion for cases with physician consultation and $1.7 billion for cases requiring hospitalization (cost estimates were adjusted to 2000 U.S. dollars using the consumer price index for medical services noted in Chapter 4). Cases of disease are not reported as mild, moderate or severe in the WBDOSS, but we designated a proportion of cases in each category based on the limited medical treatment data available in the WBDOSS. For the COI analysis, we defined severe cases as individuals who died or were hospitalized due to an infection related to a WBDO (see Chapter 4 for further information). Moderate cases included individuals who visited emergency rooms or physicians and mild cases were the remaining reported cases of illness. Our disease burden approach adjusted for under-reported emergency room and physician visits but did not consider under-reporting of mild cases. The degree of under-reporting among mild cases could not be estimated since most of these cases do not seek medical attention, which limited our ability to stratify the disease burden analyses by severity of illness categories.

The cases of illness reported to the WBDOSS most likely include acute cases of gastrointestinal disease and, therefore, our analyses likely underestimate the burden associated with complications of infections (e.g., hemolytic uremic syndrome following *E. coli* O157). In addition, the lack of data on immune status and infrequent reporting of age limited our ability to quantify effects of chronic waterborne disease that may have occurred in susceptible populations such as the elderly or patients with HIV/AIDS. Another limitation of the analyses was that the direct costs did not include certain categories of expenditures. Specifically, the estimates do not include the other costs of seeking care such as transportation and costs of hiring caregivers. Nor do they include the costs of protective or averting behaviors such as bottled water or filters.

Accurate case enumeration is contingent on a thorough epidemiologic investigation and quantification of the total population exposed during an outbreak. In addition to actual reported case counts in the WBDOSS, local investigators may provide an estimated count based on the reported attack rate and information on the population exposed to the suspected contamination source. Since this information is not always known for each outbreak, this results in variability in the case estimation approach across outbreaks. We used the number of cases of illness per outbreak as reported in the WBDOSS, including the actual counts reported for 70% of WBDOs. Using the actual reported case numbers may lead to under-reporting in some of the outbreaks. Identification of cases of illness can also be affected by the magnitude of and publicity surrounding an outbreak as over-reporting of infectious disease symptoms has been previously noted in retrospective epidemiologic studies (Wheeler et al., 1999).

We examined the potential for under- and over-reporting of gastroenteritis cases associated with the Milwaukee cryptosporidiosis outbreak and also assessed the impact of variable disease severity estimates for average duration of illness. This outbreak accounted for $461 million of the $610 million total burden for all reported outbreaks during 1971-2000 and was based on 403,000 reported cases, 9 days average duration of illness and a monthly background diarrheal incidence of 0.5% among residents of the greater Milwaukee area. Given the magnitude of burden attributable to the Milwaukee WBDO, we examined the extent that alternative values would impact the overall burden. If a case estimate of 370,000 and disease duration of 3 days is assumed, the alternative disease burden was $383 million. If a case estimate of 435,000 and disease duration of 9 days is assumed, the alternative disease burden was $472 million. Based on these alternative estimates, the Milwaukee outbreak would still account for most of the monetary burden estimated from reported WBDOs. This is largely due to the impact of mortality on disease burden, since the number of deaths was held constant in this sensitivity analysis.

Most of the cases of illness reported to the WBDOSS were assumed to be primary cases, but we could not distinguish the extent to which secondary cases due to person-to-person transmission impacted the number of reported cases. The likelihood that secondary cases were detected and reported in epidemiologic outbreak investigations is dependent on the latency and incubation periods of the etiologic agent and the time frame of the outbreak investigation. WBDO investigations of outbreaks of longer duration including those based on retrospective community surveys are more likely to detect secondary cases unless specifically restricted in time to target primary cases. For example, secondary transmission in the Milwaukee outbreak has been estimated at 10% for the general population (Eisenberg et al., 2005) and was likely more prevalent among the elderly (Naumova et al., 2003). While extensive epidemiologic investigations may better reflect the true magnitude of an outbreak, including secondary cases may limit comparisons of the disease burden across etiologic agent groups and may limit the potential to generalize reported epidemiologic measures based on limited outbreak data.

The magnitude of under- or over-reporting of epidemiologic measures in the WBDOSS is unknown; therefore, we used sensitivity analyses to examine the extent that under- or over-reporting may influence our monetary estimates. We demonstrated that the total monetary burden was most sensitive to estimates of person-days ill and mortality. The influence of person-days ill, largely due to its use in productivity loss calculations for both caregiver and the ill person, accounted for most of the COI contribution to disease burden. These data further emphasize the need for accurate estimation of the number of cases and the duration of illness for WBDOs since they determine the contribution of person-days ill to disease burden estimates.

Disease burden is sensitive to the large monetary value ascribed to saving one generic life (e.g., $6.43 million/death). This value is based on a review of VSL studies that served as the basis for the monetary burden approach (U.S. EPA, 2000a). A limitation of this approach was that it did not consider the variation across studies. Although transferring VSL estimates is standard practice for U.S. EPA analyses, our approach does not address the differences in the risk and population characteristics (U.S. EPA, 2000a). For example, individuals may value occupational mortality risks differently from environmental risks. It is also important to note that we are using VSL estimates to describe the monetary burden of WBDO deaths, rather than to estimate the value of a risk reduction. The use of sensitivity analyses have been recommended to address the uncertainty in VSL estimates (U.S. EPA, 2000a); therefore, we examined the impact on the WBDO disease burden by using the distribution of the VSL described in Chapter 6 and mortality estimate distributions predicted for different etiologic agents. This analysis, based on the Weibull distribution and a mean of 108 deaths associated with WBDOs, resulted in an additional $260 million attributable to premature mortality compared to the disease burden based on the VSL central tendency approach using a mean of 66 deaths presented in Chapters 4. This analysis showed that the variability and uncertainty in VSL values is a significant source of the overall uncertainty in the estimated burden associated with premature mortality.

7.2. CONCLUSIONS

In addition to mandating actions to improve the microbiological quality of water, the 1996 amendments to the SDWA also mandated benefit-cost analyses for newly proposed regulations. Estimates of the incidence and severity of diseases attributable to drinking water as well as an assessment of the social and economic costs of the occurrence of these diseases are essential for the conduct of benefit-cost analyses. Three approaches are typically used to develop a waterborne disease incidence estimate: (1) using risk assessment methods that utilize pathogen exposure information and dose-response algorithms (2) generalizing epidemiologic study results to the general population and (3) analyzing public health surveillance data. These approaches, along with examples of estimates of endemic waterborne risks, are discussed in detail in a special issue of the *Journal of Water and Health* to be published in 2006.

Economic analyses of new water regulations in the U.S. primarily focus on evaluating endemic disease incidence that occurs when treatment and distribution systems are functioning according to established practices (i.e., not under treatment failure or deficiency situations). The U.S. EPA has largely relied on risk assessment methods to develop the endemic disease incidence estimates needed for benefit-cost analyses of proposed drinking water regulations. In the future, these risk assessment estimates of burden will be complemented and strengthened by the SDWA-mandated "national estimate" of waterborne disease. This mandate requires the U.S. EPA and the CDC to jointly conduct pilot waterborne disease occurrence studies in at least five major public water supply systems (U.S. EPA, 1998); one study already conducted has used an epidemiologic intervention study design approach (e.g., Colford et al., 2005).

In contrast to those Agency efforts focused on examining the endemic disease burden, we demonstrate a methodology for assessing the burden associated with waterborne outbreaks. Our methodology relies on the third method described above for estimating disease burden: analyzing surveillance data. Although this approach, like the others, is affected by the accuracy of available data and the limitations of the methodology that was developed, it provides additional insight for evaluating the overall burden of waterborne disease in the U.S. This analysis provides a range of estimates of the burden of reported waterborne outbreaks from 1971-2000, and this information contributes to the body of knowledge that regulators need for informed decision-making. The disease burden approach presented here allows for comparison of disparate public health concerns through metrics that incorporate indicators of disease severity, costs and societal values. The analysis presented here also examined the potential utility of using passive surveillance systems to develop disease burden estimates; the outcome of this examination reinforces the importance of collecting more detailed epidemiologic data, including disease severity measures to aid future disease burden efforts.

Although we were able to quantify the burden associated with reported WBDOs, a main limitation of the analyses was the inability to determine the potential impact of unrecognized and unreported WBDOs. Additional analyses could help identify the important characteristics of unrecognized WBDOs that may aid in the estimation of the potential impact of unrecognized and unreported WBDOs on waterborne disease burden. Developing categorization approaches for determining the likely etiologic agent or group associated with AGI outbreaks would also help to further refine the disease burden estimates that are presented here. These efforts could help address some of the uncertainty in the waterborne disease burden developed here.

7.3. RECOMMENDATIONS

This waterborne disease burden analysis was effective at determining the utility of the WBDOSS for estimating disease burden. To address some of the uncertainty in the disease burden estimates, additional data are needed including specific improvements in the WBDO surveillance system. The following recommendations are suggested to improve waterborne disease burden estimates in the future:

- Information needed to determine disease burden should be specifically requested on CDC 52.12. This includes physician visits, emergency room visits and the age distribution of the identified cases.
- Efforts are needed to standardize outbreak reporting to allow for comparisons of disease burden between reported WBDOs. Information should be requested about the method used to determine the number of actual and estimated cases for each outbreak.

- Information should also be requested about the method used to ascertain the number of deaths, hospitalizations and illness duration for each reported outbreak. Suggested questions include: Were hospitalizations based on admission or discharge diagnosis? Was infection from the waterborne source a contributing cause or the underlying cause of death? What time period was considered for the WBDO? How many patients were interviewed to obtain the illness duration information?

- Additional focused studies in selected outbreaks could improve the estimates of the number of mild cases not seeking formal care and the costs (self-medication and productivity losses) associated with them.

- Additional efforts, such as linking disease surveillance systems with water quality monitoring systems, are needed to examine the effectiveness of current water quality surveillance activities.

- Studies should be designed and conducted to assess the effectiveness of the current WBDO surveillance system in detecting waterborne disease outbreaks.

- Studies should also be conducted to help estimate the number and type of WBDOs that may be unrecognized.

- Death certificate analyses should be conducted among sensitive populations for severe outbreaks to determine increases in mortality that may be attributable to waterborne disease outbreaks.

In addition to the aforementioned recommendations, additional sensitivity analyses are needed to examine the effect that alternative assumptions might have on the disease burden estimates presented here. This could help identify the components that have the greatest potential impact on disease burden and could further delineate specific research needs for the future.

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APPENDIX A

THE WATERBORNE OUTBREAK SURVEILLANCE SYSTEM

A.1. INTRODUCTION

National statistics on waterborne outbreaks have been compiled and reported in the United States since 1920. In 1971, the CDC, the U.S. EPA, and the Council of State and Territorial Epidemiologists began a collaborative, passive surveillance program for the collection of data on the occurrence and causes of waterborne. State, territorial, and local public health agencies have the primary responsibility for detecting and investigating waterborne outbreaks, and they voluntarily report them to the CDC on Standard Form 52.12.[1] Occasionally, the CDC and U.S. EPA are invited to participate in the investigation.

The standard reporting form, which has been used since 1974, solicits data on the characteristics of the outbreak (including the number of ill persons, dates of illness onset, and location that define the outbreak), results from epidemiologic studies, testing of water and patient samples, and contributory issues, such as water distribution, disinfection, and environmental factors. CDC annually requests reports from state and territorial public health agencies, and from the Freely Associated States (including Republic of Marshall Islands, Federated States of Micronesia, and Republic of Palau). Additional information regarding the water quality, water system and treatment is obtained from the state's drinking water agency as needed.

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[1] Appendix B shows various forms used during 1971-2002. The current form can be found at www.cdc.gov/healthyswimming/downloads/cdc_5212_waterborne.pdf.

Surveillance summaries of reported waterborne outbreaks have been published biennially or annually since 1973 (CDC, 1973, 1974, 1976a,b, 1977, 1979, 1980, 1981, 1982a,b, 1983, 1984, 1985; St. Louis, 1988; Levine and Craun, 1990; Herwaldt et al., 1991; Moore et al., 1993; Kramer et al., 1996; Levy et al., 1998; Barwick et al., 2000; Lee et al., 2002; Blackburn et al., 2004). The surveillance system includes outbreaks associated with drinking water, recreational water, and other types of water exposures. Numerical and text data are abstracted from the outbreak form and supporting documents and entered into a database maintained by CDC and U.S. EPA. For the analyses in this report, we used information from drinking water outbreaks reported during the 30-year period 1971-2000. Although surveillance information was recently made available for 2001-2002, the detailed information was not readily available for our analyses.

A.2. USES OF THE WATERBORNE OUTBREAK SURVEILLANCE DATA

WBDO surveillance efforts have the following objectives: (1) characterize the epidemiology of waterborne outbreaks; (2) identify the etiologic agents that caused waterborne outbreaks and determine why the outbreaks occurred; (3) encourage public health personnel to detect and investigate waterborne outbreaks; and (4) collaborate with local, state, federal, and international agencies on initiatives to prevent waterborne disease. The surveillance data have been helpful in identifying the important waterborne pathogens and evaluating the relative degrees of risk associated with different types of source water and systems, the adequacy of current technologies and regulations (Lee et al., 2002; Blackburn et al., 2004).

A.2.1. Classification of Waterborne Outbreaks and Water Systems. Two criteria must be met for an event to be defined as a waterborne outbreak (Lee et al., 2002; Blackburn et al., 2004). First, two or more persons must have experienced a similar illness after exposure to water. This criterion is waived for single cases of laboratory-confirmed primary amebic meningoencephalitis and for single cases of chemical poisoning if water-quality data indicate contamination by the chemical. Second, epidemiologic evidence must implicate water as the probable source of the illness. Epidemiologic evidence is important because waterborne pathogens of concern in the United States may have multiple transmission routes, including person-to-person contact, contact with fomites, and ingestion of contaminated food as well as contaminated water. The evidence must associate water with illnesses before it can be considered as a waterborne outbreak.

The CDC and U.S. EPA classify reported waterborne outbreaks according to the strength of the evidence implicating water as the vehicle of transmission (Lee et al., 2002; Blackburn et al., 2004). The classification scheme is based on the epidemiologic and water-quality data provided by the investigators. Epidemiologic data are weighted more than water-quality data. Although outbreaks without water-quality data might be included, reports that lack epidemiologic data are not. Single cases of primary amebic meningoencephalitis or chemical poisoning are not classified according to this scheme. The classification system was developed in 1989 (Herwaldt et al., 1991). Before 1989, an informal, but similar, approach was used to evaluate the evidence. A classification of I indicates that adequate epidemiologic and water-quality data were reported (Table A-1); however, "the classification does not necessarily imply whether an investigation

TABLE A-1

Classification of Investigations of Waterborne Disease Outbreaks in the United States

Class	Epidemiologic Data	Water-quality Data
I	Adequate Data were provided about exposed and unexposed persons, and the relative risk or odds ratio was $\geq$2, or the p-value was $\leq$0.05	Provided and adequate Historical information or laboratory data (e.g., the history that a chlorinator malfunctioned or a water main broke, no detectable free-chlorine residual, or the presence of coliforms in the water)
II	Adequate	Not provided or inadequate (e.g., laboratory testing of water not done)
III	Provided, but limited Epidemiologic data were provided that did not meet the criteria for Class I, or the claim was made that ill persons had no exposures in common besides water, but no data were provided.	Provided and adequate
IV	Provided, but limited	Not provided or inadequate

was optimally conducted" (Lee et al., 2002) or that all information requested on the report form was provided. Although anecdotal reports of possible waterborne illness are not included, outbreaks with limited epidemiologic evidence may be included (Craun et al., 2001). During 1992-1996, 29% of the reported WBDOs had limited epidemiologic evidence (classification III); in none of the WBDOs were both the epidemiologic and water quality evidence limited (classification IV) (Craun et al., 2001). A classification of II or III should not be interpreted to mean that investigations were inadequate or incomplete (Lee et al., 2002; Blackburn et al., 2004). Outbreaks and the resulting investigations occur under various circumstances, and not all outbreaks can or should be rigorously investigated (Lee et al., 2002; Blackburn et al., 2004). In addition, outbreaks that affect few persons are more likely to receive a classification of III, rather than I, on the basis of the relatively limited sample size available for analysis (Lee et al., 2002; Blackburn et al., 2004). By establishing guidelines to include WBDOs with limited evidence, investigators are encouraged to report outbreaks which may have been difficult to investigate or where some of the findings may not be conclusive (Craun et al., 2001).

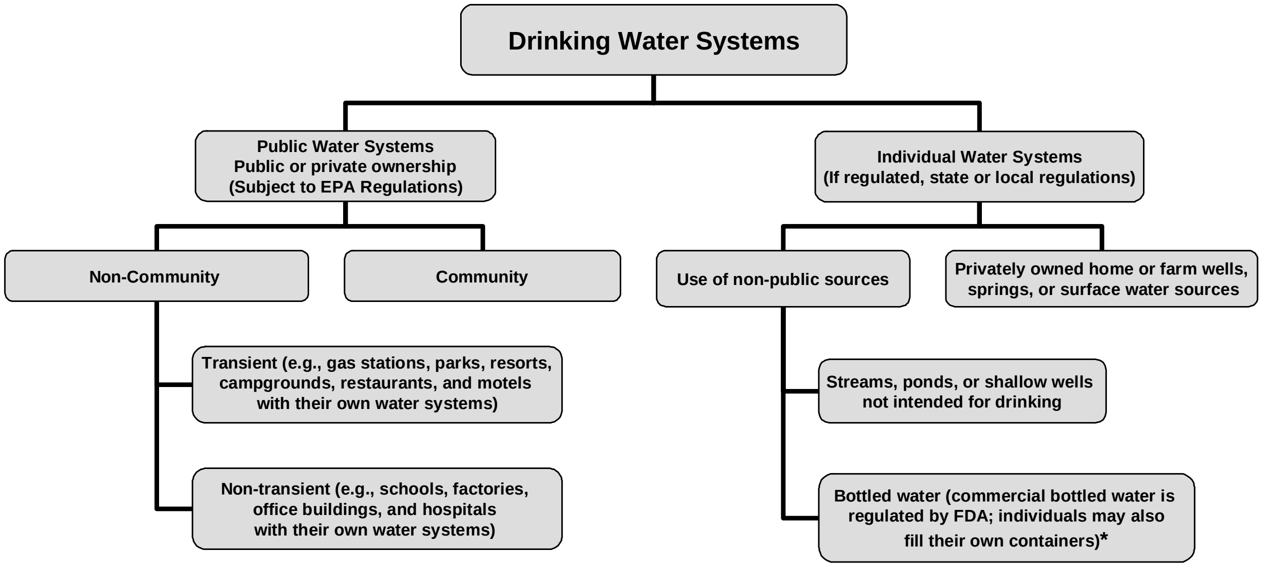
The CDC and U.S. EPA also classify each water system associated with a waterborne outbreak as having one of the following deficiencies: untreated surface water; untreated groundwater; treatment deficiency (e.g., temporary interruption of disinfection, inadequate disinfection, and inadequate or no filtration); distribution system deficiency (e.g., cross-connection, contamination of water mains during construction or repair, and contamination of a storage facility); and unknown or miscellaneous deficiency (e.g., contaminated ice, faucets, containers, or bottled water).

Water sources are identified as either surface water, groundwater, or mixed (both surface water and groundwater sources). Public drinking water systems that may be associated with outbreaks are classified as either community or noncommunity based on definitions of the SDWA; drinking water-associated outbreaks involving private, individual water systems are also tabulated (Figure A-1). Individual water systems serve families that do not have access to a public system. Drinking water outbreaks are also associated with the ingestion of water not intended for consumption, contaminated bottled water, and contamination of water or ice contaminated at its point of use (e.g., a contaminated water faucet or serving container). Waterborne outbreaks associated with cruise ships are not included in the waterborne outbreak surveillance system.

A.3. CASES OF ILLNESS AND SEVERITY OF ILLNESS

In the surveillance system, *the primary unit of analysis is an outbreak, not an individual case of a waterborne disease*. However, information is requested on the report form about the actual and estimated numbers of cases of illness, cases hospitalized, and fatalities. The report form also requests information about the actual and estimated numbers of persons exposed (at risk), incubation period, duration of illness, the number of patient specimens (e.g., stool, vomitus, serum) examined and laboratory findings.

The case definition will vary among the outbreaks depending upon the suspected etiology and the signs and symptoms that are considered important by each investigator. The report form requests information about patient histories and the number of persons with various symptoms. The symptoms highlighted on the report form include diarrhea, vomiting, cramps, fever, nausea, rash, and conjunctivitis.



*Footnote: In some instances, bottled water is used in lieu of a community supply or by non-community systems

FIGURE A-1

Types of Drinking Water Systems Used for Outbreak Classification

Information about the number of stools per day may also be used to define a case, and stools may be further described as watery, loose, or containing mucus or blood (CDC 52.12; Benenson, 1995). If a separate investigative report is enclosed, the specific case definition is usually provided. Otherwise, the case definition must be assumed from information provided on the report form. The report form specifically requests information about the number of persons with diarrhea at a frequency of three stools per day or diarrhea with an alternative definition to be provided by the investigator. The report form also requests information about a confirmed or suspected etiology.

The information requested on the standard report form can help describe the cases and impact associated with a specific outbreak, but investigators may not provide complete information about all of the measures that are considered important for estimating the outbreak's impact. The primary purpose of an investigation is to identify the cause of the outbreak so that steps can be taken to stop the outbreak, and this presumes that the recognition of an WBDO is timely. If water is implicated in an outbreak investigation where cases are continuing to occur, the focus will be on understanding the circumstances that led to the outbreak and developing corrective measures to ensure that the water is safe. In addition, WBDOs may be retrospectively investigated to identify the etiologic agent and water system deficiencies. In this case, limited information may be available to the investigator. Thus, identification of the full impact of the WBDO may be of secondary importance, depending on the suspected etiology, population at risk, and available resources. Illnesses among travelers and tourists may be geographically dispersed making it difficult to recognize all cases. Also, there has been controversy surrounding reported WBDOs and the possible over estimation of cases (Craun et al., 2001).

As previously noted, the cases reported in the surveillance system may be based on limited information. In addition, cases may be reported in several ways. Reported cases may be either an actual or estimated number, and the reported cases may be based on signs and symptoms or may be confirmed by laboratory analysis of specimens. If both actual and estimated case counts are included on the outbreak report form, the CDC tabulates the estimated case count if the study population was sampled randomly or the estimated count was calculated by using the attack rate (Lee et al., 2002).

Recurring methodological problems may also limit the information about waterborne transmission. For example, an outbreak may impact relatively few persons making it difficult to identify a waterborne association, or there may be a large number of asymptomatic infections or mild illnesses that are not able to be identified because of the lack of resources. In addition, not all WBDO investigations identify both primary and secondary cases to assess the full impact of the outbreak. Primary cases are persons who are exposed to and infected by contaminated water; secondary cases are persons who are infected by and became ill after contact with primary case-patients. Primary cases can be a source of secondary infection, since some waterborne pathogens are easily spread by person-to-person transmission (Craun et al., 2001). The standard report form does not distinguish between primary and secondary cases; this information is available only from comments that may be noted on the remarks section of the report form or separate reports attached to the form. If primary cases and secondary cases are reported, only primary cases are included in the database.

A.4. LIMITATIONS OF THE SURVEILLANCE DATA

The key limitation of the data collected as part of the surveillance system is that the information pertains to *outbreaks* of waterborne disease. The reported statistics do not include *endemic or sporadic* cases of waterborne disease that are not recognized as an outbreak, and the epidemiologic trends and water-quality concerns observed in outbreaks might not necessarily reflect or correspond with trends associated with endemic waterborne illness. Endemic disease is the usual ongoing prevalence of a disease in a population or geographic area, and specifically-designed epidemiologic studies are needed to provide a quantitative estimate of the risk attributable to drinking water. The CDC and U.S. EPA are currently conducting epidemiologic studies of endemic waterborne disease risks, and these risks are not considered in our analyses.

Since the surveillance is passive and outbreak reporting is voluntary, the surveillance statistics represent only a portion of the waterborne outbreaks that occur in the United States. The thoroughness of reporting varies, and the epidemiologic information (e.g., population exposed, attack rates, cases and severity of illness) may be inconsistent or sparse. Thus, not all of the cases that occurred may be included in the outbreak reports. As previously noted, cases of Illness may also be overestimated due to recall or other epidemiologic biases or inadequate information about the size of the exposed population (Craun and Frost, 2002; Craun et al., 2001; Cooper et al., 1995). For example, in the Milwaukee cryptosporidiosis outbreak, the largest waterborne outbreak reported in the U.S., an extensive investigation was conducted and considerable efforts went into estimating the cases of illness and their severity (Mac Kenzie et al., 1994; Hoxie et al., 1996; Naumova et al., 2003; Proctor et al., 1998; McDonald et al., 2001). There are few outbreaks where similar efforts were expended to estimate the number of cases and their severity. However, even with these efforts, there is still uncertainty about the outbreak's impact on Milwaukee residents. Hunter and Syed (2001) suggest that cases attributed to the waterborne outbreak were greatly overestimated, and a study of *Cryptosporidium*-specific antibody responses in children by McDonald et al. (2001) suggest that infection was much more widespread than previously appreciated. Unfortunately, McDonald et al. provided no information about symptoms or severity of cryptosporidiosis in the infected children.

In addition, not all waterborne outbreaks are recognized and investigated and not all investigated outbreaks are reported to CDC or U.S. EPA. For example, outbreaks occurring in national parks, tribal lands, or military bases may not be reported to state or local authorities (Blackburn et al., 2004). There are few estimates of the number of waterborne outbreaks that may go unrecognized and unreported (Craun, 1986; Hopkins et al., 1985), and studies have not been performed that assess the sensitivity of the surveillance system regarding unrecognized and unreported outbreaks (Blackburn et al., 2004). Thus, any estimates of underreporting of outbreaks should be viewed with caution.

Blackburn et al. (2004) suggest that data in the surveillance system markedly underestimate the true incidence of waterborne outbreaks. In part, this is because multiple factors influence whether waterborne outbreaks are recognized and investigated by local or state public health agencies. These include public awareness of the outbreak, availability of laboratory testing, requirements for reporting diseases, and resources available to the local health departments for surveillance and investigation of probable outbreaks. In addition, changes in the capacity of local and state public health agencies and laboratories to detect an outbreak might influence the numbers of outbreaks reported in each state relative to others. Thus, the states with the majority of outbreaks reported during this period might not be the states where the majority of outbreaks actually occurred. An increase in the number of outbreaks reported could either reflect an actual increase in outbreaks or a change in sensitivity of surveillance practices. As with any passive surveillance system, accuracy of the data depends greatly on the reporting agencies (state, local and territorial health departments in this case). Thus, independent of the recognition or investigation of a given outbreak, reporting bias can influence the final data.

Most likely to be recognized and investigated are outbreaks of acute illness characterized by a short incubation period, outbreaks that result in serious illness or symptoms requiring medical treatment, and outbreaks of recently recognized etiologies for which laboratory methods have become more sensitive or widely available (Blackburn et al., 2004). Increased reporting often occurs as etiologies become better recognized, water system deficiencies identified, and state surveillance activities and laboratory capabilities increase (Frost et al., 1995, 1996; Hopkins et al., 1985). Recommendations for improving waterborne disease outbreak investigations include increased laboratory support for clinical and water analyses, enhanced surveillance activities, and assessment of sources of potential bias (Craun et al., 2001; Frost et al., 2003; Hunter et al., 2003).

During the 30-year surveillance period (1971-2000) included in our analysis, an etiologic agent was not identified in 55% of the reported waterborne outbreaks of infectious disease. The identification of the etiologic agent of a waterborne outbreak depends on the timely recognition of the outbreak so that appropriate clinical and environmental samples can be collected. Additionally, the laboratory involved must have the capability to test for a particular organism in order to detect it. For example, routine testing of stool specimens at laboratories will include tests for the presence of enteric bacterial pathogens and might also include an ova and parasite examination. However, *Cryptosporidium spp.*, among the most commonly reported waterborne pathogens, is often not included in standard ova and parasite examinations, and thus must be specifically requested (Jones et al., 2004). Additionally, though norovirus testing is being performed more commonly, testing for other viral agents is rarely done (Blackburn et al., 2004).

Outbreaks classified as AGI are likely caused by a variety of etiologic agents. The symptoms and severity of illness associated with these outbreaks can vary based on the etiologic agent. Testing, when conducted, may not identify an agent. For example during 1999-2000, laboratory testing for enteric pathogens was conducted in five of the 17 AGI outbreaks; stool specimens were negative for parasitic and bacterial pathogens in four outbreaks. In the fifth AGI outbreak affecting only two persons, stool specimens tested negative for *Giardia intestinalis* but positive for *Blastocystis hominis*. Whether *B. hominis* was the cause of the reported illness was unclear because its pathogenicity has been debated in the scientific community (Lee et al., 2002). Suspected pathogens were noted by investigators of the following four additional AGI outbreaks on the basis of symptoms of illness: norovirius was suspected in one outbreak and *G. intestinalis* in one outbreak; a bacterial pathogen and an unknown chemical were each suspected in the two remaining outbreaks.

Finally, collection of water-quality data which can help determine contamination sources or identify the waterborne pathogen depends primarily on local and state statutory requirements, the availability of investigative personnel, and the technical capacity of the laboratories that test the water. Not all reported waterborne outbreaks have adequate information about waterborne pathogens, indicators of fecal contamination, or likely sources of the contamination.

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APPENDIX B

OUTBREAK INVESTIGATION METHODS
ENTERIC WATERBORNE DISEASE OUTBREAKS IN DRINKING WATER 1971-2000

TABLE B-1

Case Counts Reported in Enteric Waterborne Disease Outbreaks in Drinking Water by Time Period, 1971-2000

How Cases Were Reported	1971 to 1980		1981 to 1990		1991 to 2000	
	Number of Reported Outbreaks	Number of Reported Cases	Number of Reported Outbreaks	Number of Reported Cases	Number of Reported Outbreaks	Number of Reported Cases
Cases, Actual	192	16,817	171	13,467	100	5,959
Cases, Estimated	49	52,162	56	49,587	43	426,181
Unknown	44	5,552	8	182	2	55
Total	285	74,531	235	63,236	145	432,195

TABLE B-2

Case Counts Reported in Enteric Waterborne Disease Outbreaks in Drinking Water by Type of System, 1971-2000

How Cases Were Reported	Community		Individual		Non-community	
	Number of Reported Outbreaks	Number of Reported Cases	Number of Reported Outbreaks	Number of Reported Cases	Number of Reported Outbreaks	Number of Reported Cases
Cases, Actual	170	18,421	64	944	229	16,878
Cases, Estimated	72	491,786	6	409	70	35,735
Unknown	12	4,063	12	155	30	1,571
Total	254	514,270	82	1,508	329	54,184

TABLE B-3

How Reported Cases Were Estimated in Enteric Waterborne Disease Outbreaks in Drinking Water by Time Period, 1971-2000

How Cases Were Estimated	1971 to 1980		1981 to 1990		1991 to 2000	
	Number of Reported Outbreaks	Number of Reported Cases	Number of Reported Outbreaks	Number of Reported Cases	Number of Reported Outbreaks	Number of Reported Cases
Cohort survey	26	21,419	23	20,661	15	2,191
Unknown	8	14,797	15	7,445	6	1,885
Guess	9	2,051	11	4,053	13	1,847
Random survey	5	12,695	6	17,343	8	420,188
Cohort and physician survey	1	1,200	1	85	0	0
Physician Survey	0	0	0	0	1	70
Total	49	52,162	56	49,587	43	426,181

TABLE B-4

How Reported Cases Were Estimated in Enteric Waterborne Disease Outbreaks in Drinking Water by Type of System, 1971-2000

How Cases Were Estimated	Community		Individual		Non-community	
	Number of Reported Outbreaks	Number of Reported Cases	Number of Reported Outbreaks	Number of Reported Cases	Number of Reported Outbreaks	Number of Reported Cases
Cohort survey	33	24,800	0	0	31	19,471
Unknown	15	17,038	1	150	13	6,939
Guess	6	457	4	174	23	7,320
Random survey	17	448,291	0	0	2	1,935
Cohort and physician survey	1	1,200	1	85	0	0
Physician Survey	0	0	0	0	1	70
Total	72	491,786	6	409	70	35,735

TABLE B-5

How Case Counts Were Obtained in Enteric Waterborne Disease Outbreaks in Drinking Water by Time Period, 1971-2000

How Actual Cases Were Obtained	1971 to 1980		1981 to 1990		1991 to 2000	
	Number of Reported Outbreaks	Number of Reported Cases	Number of Reported Outbreaks	Number of Reported Cases	Number of Reported Outbreaks	Number of Reported Cases
Cohort survey	96	7,310	88	4,062	59	4,328
Unknown	41	5,867	41	5,046	6	338
All population at risk surveyed	38	2,008	22	617	30	814
Cohort and physician survey	12	1,457	8	1,912	2	203
Laboratory positive cases	3	39	6	759	2	153
Physician, hospital survey	2	136	2	15	1	123
Random survey	0	0	4	1,056	0	0
Total	192	16,817	171	13,467	100	5,959

TABLE B-6

How Case Counts Were Obtained in Enteric Waterborne Disease Outbreaks in Drinking Water by Type of System, 1971-2000

How Actual Cases Were Obtained	Community		Individual		Non-community	
	Number of Reported Outbreaks	Number of Reported Cases	Number of Reported Outbreaks	Number of Reported Cases	Number of Reported Outbreaks	Number of Reported Cases
Cohort survey	95	6,196	23	541	125	8,963
Unknown	36	7,148	6	35	46	4,068
All population at risk surveyed	13	770	33	364	44	2,305
Cohort and physician survey	13	2,324	1	2	8	1,246
Laboratory positive cases	7	912	1	2	3	37
Physician, hospital survey	2	15	0	0	3	259
Random survey	4	1,056	0	0	0	0
Total	170	18,421	64	944	229	16,878

APPENDIX C

ANNUAL ESTIMATES OF EPIDEMIOLOGIC AND MONETARY DISEASE BURDEN, 1971-2000

TABLE C-1

Reported and Projected Epidemiological Burden by Year

Year	Outbreaks	Cases	Reported Person-Days Ill	Projected Person-Days Ill	Physician Visits Reported	Physician Visits Projected	Emergency Room Visits Reported	Emergency Room Visits Projected	Hospital Visits Reported	Hospital Visits Projected	Deaths Reported	Deaths Projected
1971	18	5,179	14,854	19,770	96	665		575	63	63	1	1
1972	27	1,448	645	8,180	15	241		146	20	20	0	0
1973	25	1,762	1,482	12,151	2	239		163	193	193	2	2
1974	20	8,087	26,613	34,282		1,761		466	214	214	0	0
1975	21	10,842	36,580	40,512	627	1,063	91	530	61	61	0	0
1976	32	5,033	7,891	24,373	123	623	79	464	105	105	0	0
1977	28	3,227	1,426	21,518		575		255	21	21	0	0
1978	30	11,389	53,690	57,919		2,070	179	547	24	24	0	0
1979	38	9,817	29,955	89,775	6	2,213	102	571	15	15	0	0
1980	46	17,747	7,437	78,291	3	2,183	5	1,557	73	73	0	0
1981	32	4,726	870	25,212	160	479		290	19	19	0	0
1982	41	3,569	6,787	21,684	9	557		267	57	57	0	0
1983	42	21,033	43,663	84,951	47	2,712	1	1,963	60	60	0	0
1984	24	1,770	7,022	13,776	4	357		85	12	12	0	0
1985	20	1,914	1,768	13,395		335	4	129	102	102	0	0
1986	19	1,505	3,311	8,856		194		97	18	18	0	0
1987	14	22,122	6,388	145,004		1,546	540	1,159	49	49	0	0

TABLE C-1 cont.													
Year	Outbreaks	Cases	Reported Person-Days Ill	Projected Person-Days Ill	Physician Visits Reported	Physician Visits Projected	Emergency Room Visits Reported	Emergency Room Visits Projected	Hospital Visits Reported	Hospital Visits Projected	Deaths Reported	Deaths Projected
1988	15	2,160	3,114	8,722		238		170	15	15	0	0
1989	13	2,670	3,364	12,641	97	280		130	49	49	4	4
1990	15	1,767	840	8,679	4	243	4	177	10	10	0	0
1991	16	12,981	34,255	34,572		1,347		1,417	30	30	0	0
1992	24	4,840	37,137	39,626	48	441		283	16	16	0	0
1993	12	404,114	3,635,960	3,637,297	20,283	20,355		11,749	4,432	4,432	57	57
1994	14	1,310	3,383	10,161		189		99	10	10	0	0
1995	15	2,492	7,102	27,099	2	560	8	120	21	21	0	0
1996	7	843	1,477	2,928	5	77		24	5	5	0	0
1997	7	1,752	2,669	3,325		182		26	3	3	0	0
1998	10	1,703	7,475	8,727		91		53	87	87	0	0
1999	13	1,163	2,716	6,649		78		23	97	97	2	2
2000	27	997	3,052	4,779		92		40	34	34	0	0
Total	665	569,962	3,992,923	4,504,854	21,531	41,985	1,013	23,575	5,915	5,915	66	66

TABLE C-2

Reported and Projected Economic Burden by Year

Year	Physician Visit Costs Reported ($)	Physician Visit Costs Adjusted ($)	Emergency Room Visit Costs Reported ($)	Emergency Room Costs Projected ($)	Hospitalization Costs Reported ($)	Hospitalization Costs Projected ($)	Self Medication Costs Reported ($)	Self Medication Costs Projected ($)	Cost-of-Illness Prod Losses Reported ($)
1971	6,192	42,906	-	219,687	120,045	120,045	11,524	11,608	311,200
1972	968	15,551	-	55,730	46,162	46,162	3,222	3,249	14,612
1973	129	15,383	-	62,128	1,217,719	1,217,719	3,976	4,005	33,734
1974	-	113,577	-	177,973	604,941	604,941	18,024	18,191	632,235
1975	40,442	68,542	34,764	202,382	183,891	183,891	24,143	24,209	878,856
1976	7,934	40,164	30,180	177,370	319,034	319,034	11,210	11,276	185,436
1977	-	37,082	-	97,485	69,626	69,626	7,171	7,233	32,096
1978	-	133,490	68,382	208,985	73,902	73,902	25,305	25,488	1,150,298
1979	387	142,758	38,966	218,017	41,686	41,686	21,807	22,007	635,379
1980	194	140,814	1,910	594,967	231,208	231,208	39,423	39,703	157,190
1981	10,320	30,893	-	110,848	72,233	72,233	10,510	10,556	51,276
1982	581	35,936	-	101,959	153,667	153,667	7,943	8,002	240,720
1983	3,032	174,947	382	749,956	193,656	193,656	46,717	47,063	940,858
1984	258	23,007	-	32,451	39,607	39,607	3,934	3,966	153,320
1985	-	21,603	1,528	49,419	474,410	474,410	4,283	4,317	170,618
1986	-	12,541	-	36,873	57,728	57,728	3,347	3,369	76,467
1987	-	99,711	206,291	442,902	139,034	139,034	49,167	49,330	230,936
1988	-	15,336	-	64,762	41,737	41,737	4,800	4,831	67,181
1989	6,257	18,030	-	49,589	158,624	158,624	5,952	5,976	100,059
1990	258	15,690	1,528	67,576	29,114	29,114	3,927	3,957	18,888
1991	-	86,895	-	541,336	90,969	90,969	28,828	29,035	733,679
1992	3,096	28,470	-	108,151	49,609	49,609	10,754	10,804	781,588
1993	1,308,254	1,312,887	-	4,488,469	24,596,165	24,596,165	900,132	901,018	90,942,357
1994	-	12,202	-	37,756	29,879	29,879	2,911	2,933	72,835
1995	129	36,117	3,056	45,967	66,697	66,697	5,540	5,590	156,270
1996	323	4,957	-	9,010	15,487	15,487	1,873	1,881	34,051
1997	-	11,751	-	9,886	9,525	9,525	3,890	3,906	56,669
1998	-	5,863	-	20,189	344,192	344,192	3,809	3,820	183,347
1999	-	5,000	-	8,884	341,787	341,787	2,614	2,622	73,458
2000	-	5,921	-	15,369	123,576	123,576	2,225	2,234	81,367
Total	1,388,750	2,708,025	386,986	9,006,075	29,935,910	29,935,910	1,268,959	1,272,179	99,196,978

TABLE C-2 cont.									
Year	Cost-of-Illness Prod Losses Projected ($)	Cost of Caregiver Productivity Losses Reported ($)	Cost of Caregiver Productivity Losses Projected ($)	Cost-of-Illness Reported ($)	Cost-of-Illness Projected ($)	VSL Cost Reported ($)	VSL Cost Projected ($)	Total Economic Burden Reported ($)	Total Economic Burden Projected ($)
1971	881,203	24,471	218,996	473,432	1,494,445	6,430,000	6,430,000	6,903,432	7,924,445
1972	342,964	1,607	88,410	66,571	552,066	-	-	66,571	552,066
1973	1,148,163	3,280	319,561	1,258,838	2,766,960	12,860,000	12,860,000	14,118,838	15,626,960
1974	1,217,468	67,099	279,470	1,322,300	2,411,620	-	-	1,322,300	2,411,620
1975	1,108,598	110,874	187,738	1,272,968	1,775,359	-	-	1,272,968	1,775,359
1976	736,060	19,329	145,298	573,122	1,429,201	-	-	573,122	1,429,201
1977	738,542	3,040	170,778	111,933	1,120,746	-	-	111,933	1,120,746
1978	1,823,893	99,143	386,138	1,417,030	2,651,896	-	-	1,417,030	2,651,896
1979	3,042,217	51,845	702,675	790,070	4,169,361	-	-	790,070	4,169,361
1980	2,462,206	12,752	513,923	442,676	3,982,821	-	-	442,676	3,982,821
1981	724,984	11,726	130,744	156,064	1,080,258	-	-	156,064	1,080,258
1982	865,483	41,867	216,290	444,777	1,381,337	-	-	444,777	1,381,337
1983	2,765,017	81,670	600,623	1,266,315	4,531,263	-	-	1,266,315	4,531,263
1984	461,139	13,500	103,840	210,618	664,011	-	-	210,618	664,011
1985	593,730	44,570	144,354	695,409	1,287,835	-	-	695,409	1,287,835
1986	286,026	7,664	59,495	145,206	456,031	--	-	145,206	456,031
1987	3,711,700	56,056	559,355	681,484	5,002,033	-	-	681,484	5,002,033
1988	292,519	5,737	63,266	119,454	482,449	-	-	119,454	482,449
1989	424,019	14,857	89,944	285,748	746,183	25,720,000	25,720,000	26,005,748	26,466,183
1990	290,913	1,893	64,940	55,608	472,191	-	-	55,608	472,191
1991	1,034,351	61,417	203,039	914,893	1,985,626	-	-	914,893	1,985,626
1992	1,072,592	62,279	175,815	907,325	1,445,441	-	-	907,325	1,445,441
1993	95,226,904	11,819,198	13,862,845	129,566,104	140,388,287	366,510,000	366,510,000	496,076,104	506,898,287
1994	320,789	6,185	67,199	111,810	470,758	-	-	111,810	470,758
1995	872,837	14,067	188,777	245,760	1,215,986	-	-	245,760	1,215,986
1996	82,233	3,874	14,461	55,608	128,029	-	-	55,608	128,029
1997	92,241	4,631	16,027	74,716	143,337	-	-	74,716	143,337
1998	302,907	20,642	56,915	551,990	733,886	-	-	551,990	733,886
1999	261,737	9,631	54,109	427,490	674,138	12,860,000	12,860,000	13,287,490	13,534,138
2000	173,515	10,454	35,900	217,621	356,516	-	-	217,621	356,516
Total	123,356,953	12,685,357	19,720,927	144,862,940	186,000,069	424,380,000	424,380,000	569,242,940	610,380,069