

The role of disease burden measures in future estimates of endemic waterborne disease

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ABSTRACT

The 1996 Safe Drinking Water Act amendments require the US Environmental Protection Agency and the Centers for Disease Control and Prevention to develop a national estimate of the occurrence of waterborne infectious disease that is attributable to public drinking water systems in the United States. Much of the information for developing the national estimate will be derived from epidemiologic data, and the primary outcome of this effort will be an estimate of the number of cases of gastrointestinal illness. While quantifying the number of these cases provides some measure of waterborne disease impact, the usefulness of this measure may be limited because the full spectrum of societal impact also involves consideration of the additional effects of these diseases such as hospitalization costs and lost productivity. If decision-makers wish to compare the impact of waterborne infectious diseases to the impact of some other public health concern (e.g. to aid in resource allocation decisions), then a comparison of case numbers may prove inadequate. Case numbers alone do not provide sufficient information about the severity of different illnesses. Society may value the avoidance of a few cases of severely debilitating illness more than it values the avoidance of many cases of mild illness. In order to compare disparate public health concerns, "burden of disease" measures that incorporate indicators of disease severity, costs, or societal values may prove essential for some types of decisions. We describe epidemiologic measures of severity, quality adjusted life years (QALYs), disability adjusted life years (DALYs), willingness-to-pay, and cost-of-illness methods commonly used for burden of disease estimates, and discuss how some of these summary measures of burden might be used for waterborne disease estimates.

Key words | DALY, disease burden, gastrointestinal illness, National estimate, QALY, willingness to pay

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INTRODUCTION

The 1996 Amendments to the Safe Drinking Water Act (SDWA) require the US Environmental Protection Agency (EPA) and the Centers for Disease Control and Prevention (CDC) to develop a national estimate of waterborne infectious disease occurrence that is attributable to public

drinking water systems (US EPA 1996 [see Section 1458(d)], 1998). The epidemiologic studies that will be used to develop this national estimate have focused on identifying the number of endemic cases of gastrointestinal (GI) illness (e.g. cases of nausea, abdominal cramping, vomiting and diarrhea) that are attributable to public drinking water systems (e.g. Colford *et al.* 2005; Calderon & Craun 2006; Colford & Wade 2006; Craun & Calderon 2006; Roy *et al.*

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2006). Some public health officials believe that drinking water systems that meet regulatory standards can intermittently, or even regularly, be contaminated by pathogens, and although the concentrations of infectious organisms are expected to be very low, these contamination events may result in sporadic cases of infection or illness that are not recognized or investigated as a possible outbreak (Craun *et al.* 2006).

Many potential sources of infection (e.g. water, food, person-to-person contact) can lead to GI symptoms, and quantifying the number of cases attributable to drinking water can be a difficult task. The technical challenge of estimating waterborne disease occurrence is further exacerbated by low incidence of endemic disease anticipated in a developed nation such as the United States and by the low pathogen concentrations expected in drinking waters that comply with regulatory standards.

Data from household drinking water intervention studies in the United States (Colford *et al.* 2005) and in Canada (Payment *et al.* 1991, 1997) can be used to estimate endemic waterborne risk. The results of some community intervention studies summarized by Calderon & Craun (2006) and additional observational epidemiologic studies in the United States and other developed countries (Craun & Calderon 2006) may also be of value in estimating this risk. Messner *et al.* (2006) propose an alternate approach to estimating the endemic waterborne disease risk through use of professional scientific judgment and epidemiologic data in a Bayesian framework. Risk, along with information about the population exposed, can then be used to estimate the number of cases of GI illness attributable to public drinking water in the United States.

In addition to these endemic waterborne disease cases, hundreds to thousands of disease cases that result from drinking water outbreaks are reported each year to the CDC and EPA. Outbreak cases are often associated with contaminated drinking water that fails to meet regulatory standards because of treatment or distribution system deficiencies (Craun *et al.* 2002; Lee *et al.* 2002; Blackburn *et al.* 2004). The total incidence of disease that is attributable to drinking water, therefore, consists of both endemic and outbreak cases.

The national estimate of waterborne infectious disease occurrence that is attributable to public drinking water

systems will be valuable for making the following comparisons:

- The incidence of endemic cases across distinct drinking water sources (e.g. surface water vs. groundwater; slightly contaminated surface water vs. moderately contaminated surface water) and treatment processes (e.g. disinfected vs. not disinfected; chlorinated vs. chloraminated) to determine appropriate treatment efficacy.
- Numbers of endemic cases vs. outbreak cases to determine the relative importance of treatment efficacy and reliability.
- The relative significance of waterborne disease risk to other public health risks to aid in decisions regarding resource allocation.

The usefulness of these comparisons depends on the validity of the assumption that the distribution of symptom severity associated with cases arising from different circumstances is similar (e.g. the distribution of illness duration or hospitalization rates). Kosek *et al.* (2003) used this assumption when analyzing morbidity in their estimate of global burden of childhood diarrhea. However, when considering waterborne illness risks, symptom severity may vary significantly as a result of differences in the types of infectious organisms contaminating different drinking waters. Waterborne outbreaks in the United States demonstrate that various pathogens have caused illness of different severity (Craun *et al.* 2002; Lee *et al.* 2002; Blackburn *et al.* 2004). Thus, the alternative assumption that symptom severity varies significantly needs further investigation for endemic waterborne illness.

Differences in case severity also may limit a decision-maker's ability to compare the impact of infectious waterborne diseases with those of other public health concerns. If a community must choose between implementation of a water treatment technology that will reduce GI illness in a specific population or another public health intervention that will reduce the incidence of another disease, then it would first be necessary to determine the relative societal impact of cases of GI illness compared to cases of the other disease. Disease case enumeration alone may not offer sufficient information for evaluating that impact. For example, a health intervention that prevents

100 cases of mild childhood neurotoxicity may be considered of greater importance than an intervention that could prevent 10,000 cases of GI illness. For a decision that involved this type of comparison, illness severity would be an important consideration; case numbers alone could not fully communicate the public health impact of either concern. The usefulness of disease incidence (i.e. case counts) is limited to certain decision-making processes where the distribution of case severity and the economic consequences are similar. Many other public health decisions require a health impact metric that integrates additional data along with numbers of cases or deaths.

BURDEN OF DISEASE

In the health economics literature, the composite impact of the number of cases, the cases' severity and, in some instances, the associated economic impacts is frequently referred to as the burden of disease. In general, a burden of disease analysis includes two steps: a thorough evaluation of the epidemiologic data describing the illness and an analysis of the health effects in terms of their impact on the ill and society (Murray & Lopez 1996, 2001).

A burden analysis requires an accurate estimate of the number of cases of the illness under consideration. Epidemiologic data frequently serve as the source of this information (Kosek *et al.* 2003) although estimates derived by risk assessment methods have been used (Murray & Lopez 1996; WHO 2002). Burden analyses include a detailed critique of the strengths and weaknesses of the available epidemiologic data and comparisons of relevant epidemiologic studies (Murray & Lopez 1996, 2001). Evaluations may include examinations of the epidemiologic study objectives relative to those of the burden assessment (e.g. some waterborne outbreak investigations may not identify all of the cases that occur or all of the individuals at risk); additional risk factors for the illness being assessed; possible sources of bias or confounding that might have influenced the epidemiologic study results (i.e. internal validity); and the appropriateness of generalizing from the study population to another population of interest (i.e. external validity).

In burden analyses, case enumeration is typically followed by additional steps that examine the types of

symptoms experienced by afflicted individuals, the frequency at which these symptoms occur and their duration among the ill (Murray & Lopez 1996, Chapter 4; Gold *et al.* 1996). For example, some individuals contracting a GI illness may vomit, experience multiple diarrhea episodes, or become dehydrated. Based on these different symptoms, the degrees of disability that affect the afflicted individuals would be identified. For example, a GI illness may include enduring the pain associated with two days of severe abdominal cramping and the lost productivity associated with missing work and household tasks. Burden analyses attempt to capture and convey some of these disease impacts to decision-makers.

In some measures of disease burden, descriptions of the various impacts are then presented to individuals and groups to elicit their preferences for avoiding different impacts of an illness (because some symptoms or effects are judged to be worse than others). These preferences are elicited through social science methods and they are used to assess the change in a person's level of satisfaction or well-being caused by a health effect. If the description of the illness impacts is accurate and the method is applied appropriately, the values may be summed across individuals to measure the societal burden. If not, the estimated burden of disease may be invalid.

BURDEN MEASURES

Public health organizations, such as the CDC (2005) and the World Health Organization (WHO 2002), may employ different measures to describe disease burden. Here, we describe and provide examples of a variety of burden measures including epidemiologic measures of illness severity, summary measures of population health and monetary measures of population health (Table 1).

In the sections that follow, we highlight the aspects of illness captured by each of these burden measures. We also provide additional descriptive information on these measures and highlight the possible uses and limitations of each measure in decision-making.

Epidemiologic measures of illness severity

Primary outcome measures such as duration of illness, specific symptoms, numbers of cases and deaths, and reliance

Table 1 | Examples of disease burden measures

- **Epidemiologic measures of illness severity**

- Outcomes typically measured in epidemiologic studies of waterborne infectious diseases
 - Cases of watery diarrhea or loose stools for three or more days
 - Cases of nausea and acute vomiting
 - Cases of intestinal cramps
 - Physician visits
 - Hospitalizations
 - Deaths
- Composite measures calculated from outcome measures in epidemiologic studies
 - Person-days ill
 - Years of life lived with a disability
 - Years of life lost due to death

- **Summary measures of population health**

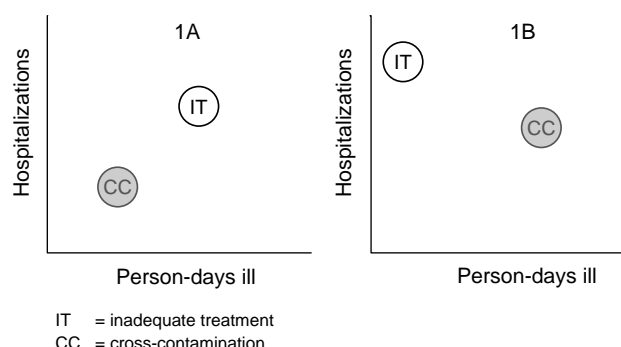
- Quality adjusted life years
- Disability adjusted life years

- **Monetary measures of population health**

- Cost of illness
- Willingness to pay (to reduce the risk of illness)

on professional medical care convey information that describes the impact of a disease (CDC 2005). For example, Payment *et al.* (1997) reported the duration of subjects' GI symptoms and Colford *et al.* (2005) reported the number of illness episodes that resulted in specific symptoms (e.g. vomiting, watery diarrhea). Primary outcome measures such as these depict the severity of the illnesses encountered in the population and can be used as measures to estimate the disease burden attributable to drinking water.

From various primary outcome measures, *composite* measures of disease burden can be calculated. These

**Figure 1** | Outcomes of a hypothetical community drinking water risk analysis.

composite measures, such as person-days ill, years lived with disability (YLD), and years of life lost (YLL), involve integration of two or more primary outcome measures. Person-days ill and YLD are calculated by summing the duration of each illness episode. YLL requires information about the age of death of individuals afflicted with a disease and the life expectancy of the population under observation. These composite measures are often reported in the epidemiologic literature.

Although primary outcome and composite measures may provide sufficient information to adequately compare different alternatives being evaluated in some decisions, these measures may prove inadequate for other decisions. Figure 1 illustrates a hypothetical example where a mix of primary outcome measures and composite measures may (1A) or may not (1B) provide sufficient insight for a decision-maker. For this example, assume that inadequate treatment (IT) of drinking water at the plant and cross-contamination (CC) in the distribution system are both identified as deficiencies that could lead to a drinking water disease outbreak. A decision is needed on whether to require a change in treatment practice to protect against IT or to improve the distribution system to protect against CC. The decision-maker wants to know which of these possible outbreak causes is associated with the larger disease burden. A microbial risk assessment predicts that the types of outbreaks that likely result from these two deficiencies (IT and CC) have roughly the same likelihood of occurring and will result in a similar number of cases¹. The risk analysis may also predict that outbreaks associated

¹ Soller (2006) provides information on the conduct of microbial risk assessments.

with IT deficiencies tend to be caused by protozoans whereas CC deficiencies tend to be caused by viruses. Given the types of pathogens, the analysis may include predictions of the expected number of hospitalizations and person-days ill that could be associated with the two different deficiencies. **Figure 1A** illustrates the number of hospitalizations (*Y* axis) and person-days ill (*X* axis) associated with the outbreaks caused by IT and CC. In **Figure 1A**, the outbreak caused by a CC is obviously less burdensome than the outbreak caused by IT because the outbreak caused by a CC is characterized by both fewer person-days ill and fewer hospitalizations. Thus, the question of which deficiency is likely to be more burdensome can be assessed in a straightforward manner. In **Figure 1B**, the outcome of the burden evaluation is not so obvious. While the outbreak caused by IT is associated with more hospitalizations than the outbreak caused by CC, it is predicted to cause fewer person-days ill. If a decision is made to recommend the infrastructure improvements to protect against CC, this implies that avoiding many person-days ill is preferred to avoiding a few hospitalizations. This could be highly subjective based on the judgment of the decision-maker.

Burden estimates based on epidemiologic measures have the advantage of not requiring further manipulation of collected data; thus, no additional uncertainties are introduced. The primary difficulty associated with epidemiologic units occurs when the decision-maker is confronted with disparate epidemiologic measures that involve trade-offs requiring judgments (e.g. **Figure 1B**). Other limitations include potential variability in case definitions across studies and inadequacy of a measure to capture the degree of disability experienced by individuals.

Summary measures of population health

Traditionally, public health decision-making relied on epidemiologic measures such as crude or age-stratified death rates (CDC 2005). The success of programs or health practices was ascertained in terms of reduced mortality. With the increase in life expectancy in the 20th century, the emphasis in public health has shifted to include both quality and length of life considerations. Measures that examined

quality of life and length of life have been developed to compare diseases, disabilities and injuries.

Broadly disparate health effects, potentially caused by a wide array of illnesses and injuries, increase the difficulty of developing measures that accurately and transparently capture societal preferences (Gold *et al.* 2002; Molla *et al.* 2003)². The methods that evaluate societal preferences also need to properly integrate measures of morbidity and mortality. We discuss these methods in this section and in the monetary measures section. These methods also need to identify the various aspects of morbidity necessary for evaluating the reduced physical and mental health functions associated with different morbidity states. For example, Torrance *et al.* (1996) identified the following aspects of morbidity requiring evaluation to characterize the impact of an illness:

- sensation
- mobility
- self-care
- participation in usual activities
- pain and discomfort
- emotion
- fertility
- cognition.

Summary population health measures attempt to integrate the burden of premature mortality (that might be expressed by a composite measure such as YLL) with the burden of decreased quality of life associated with various morbidities. Although there are a number of different types of summary population health measures, quality adjusted life years (QALYs) and disability adjusted life years (DALYs) are most commonly used. Inherent in these measures is the assumption that it is possible for individuals to rank their

² Many of these measures are based on expected utility theory, which describes how rational people may make decisions when faced with uncertainty (Raiffa 1968). Under this theory, individuals examine each choice that they have in a decision. They then identify each possible alternative outcome of each choice. The theory assumes that individuals know the likelihood of an outcome occurring and their preference for each outcome (preferences are based on an individual's utility or satisfaction for each outcome) under each choice. By multiplying the likelihood of each outcome by its utility and summing across each outcome, individuals can identify the expected utility associated with each choice. The theory assumes that, when faced with a decision, a rational individual will select the choice with the highest expected utility. However, individual behaviors can be inconsistent with this theory. For example, individuals may prefer outcomes they consider certain, relative to outcomes which are merely probable (Kahneman & Tversky 1979).

preferences for avoiding specific diseases, based on the severity of the illness experienced (i.e. some diseases are worse than others). In these measures, the impact of a disease on an afflicted individual is assessed by a utility weight.

Utility weights reflect population preferences for avoiding different health outcomes (Murray 1994; Gold *et al.* 1996; US EPA 1999; Hammitt 2002); these preferences are quantified using a 0 to 1 scale³. For example, Torrance *et al.* (1996) identify a QALY utility weight of 0.97 for individuals experiencing occasional pain and discomfort that could be relieved by non-prescription drugs or a self-imposed decrease in activity level, without disrupting the individuals' normal activities. This suggests that these symptoms result in a minor decrease in the affected individuals' quality of life. In addition to the determination of a utility weight to reflect the impact of a state of health, the time spent in that health state also needs to be identified to estimate a summary population health measure. The hypothetical individual depicted in Figure 2 experiences three time periods of decreased quality of life. In the first time period, the individual experiences short-lived pain that can be relieved by common medications and quality of life is characterized by a utility weight of 0.97. In the second, the individual experiences frequent pain that, over a longer time period, can only be relieved by prescribed medications associated with a utility weight of 0.64 (Torrance *et al.* 1996); this lasts for a relatively long period of time. The final decline in health experienced by the hypothetical individual culminates in death, which is associated with a utility weight of 0.

QALYs are a type of summary population health measure originally developed to assist in health care resource allocation decisions. These are commonly used to examine the effectiveness of medical interventions (Weinstein & Stason 1977; Pliskin *et al.* 1980; Drummond *et al.* 1997). The QALYs experienced by the hypothetical individual in Figure 2 are calculated as the sum of the products of the utility weights experienced by an individual and the amount of time (e.g. number of years) of life

experienced at that utility weight. A year in perfect health equals 1 QALY. QALYs experienced by affected individuals can then be summed and compared across alternative public health policies. The policy alternative that is predicted to result in the largest number of QALYs gained is expected to improve public health the most. Additional criteria other than maximizing a population's QALYs (e.g. policy cost) could also be used to inform this decision (Hammitt 2002)⁴.

The World Health Organization uses DALYs to estimate disease burden (World Bank 1993; Murray & Lopez 1996). DALYs were developed as a unit of measure in the Global Burden of Disease Study⁵ to examine the potential effectiveness of public health interventions (Murray & Lopez 1996) and are similar to QALYs. DALYs are the sum of YLL due to illness and the time spent living with a disability (Murray & Lopez 1996) (see Figure 3). The disability component is measured as the product of the duration of an illness and the utility weight.

DALYs also use a 0 to 1 utility weight scale but, unlike QALYs, the utility weight of 0 implies a state of perfect health and 1 implies a state of health equivalent to dead. DALYs use an age-weighting function, which indicates the relative importance of healthy life at different ages. The age weights used in the World Bank report increase from birth until age 25 and decline slowly thereafter, reflecting productivity from a societal perspective. DALYs also use a time preference function that discounts the value of future health gains in order to compare the value attached to health gains made today (sometimes referred to as present value). In practice, DALYs are summed across individuals.

DALYs are the basis of many different disease burden comparisons including across different populations and across different diseases both nationally and globally (Murray & Lopez 1996; WHO 2005). Recently, Prüss *et al.* (2002) estimated the global disease burden associated with water and sanitation, primarily focusing on diarrheal outcomes. Although they note that the symptom severity

³ For QALYs, a utility weight of 1 indicates perfect health and a utility weight of 0 indicates a state of health equivalent to dead. For DALYs, the scale is reversed. A utility weight of 0 indicates perfect health (i.e. no disability) and utility weights close to 1 indicate poor health.

⁴ See Hammitt (2002) for additional information on the theoretic foundations of QALYs and DALYs and for distinctions between QALYs and willingness-to-pay measures (discussed in the next section).

⁵ The Global Burden of Disease Study emphasized the need to improve the comparability of epidemiologic studies of different diseases and risk factors and provided a consistent way to assess the health impacts across a wide range of illnesses in different populations.

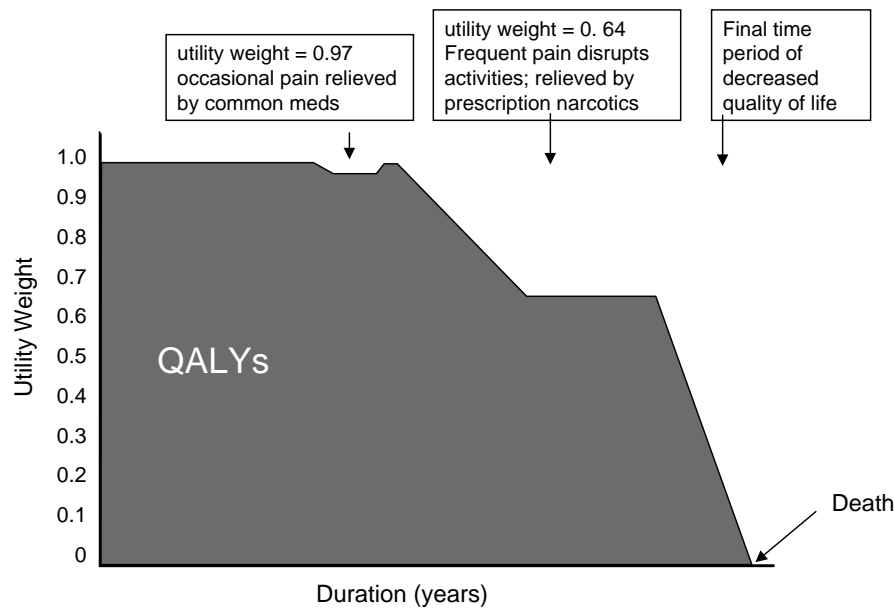


Figure adapted from Gold *et al.* (1996)
Source of utility weights Torrance *et al.* (1996)

Figure 2 | Illustrative lifespan highlighting time periods of decreased quality of life and associated utility weights.

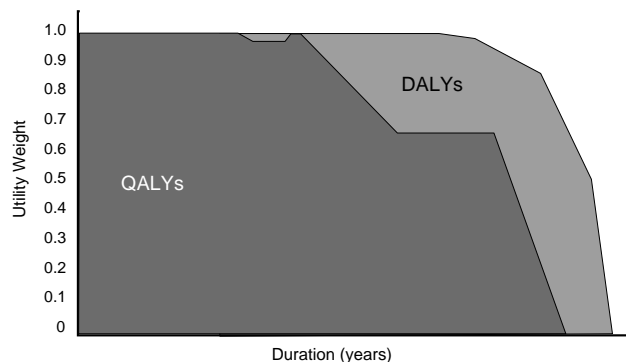
associated with different cases of diarrhea could be highly variable across individuals, they use a utility weight of approximately 0.1 in the analysis. Havelaar *et al.* (2000) also used DALYs and applied the same utility weight in their analysis of endemic cryptosporidiosis risk.

QALYs and DALYs are used in cost-effectiveness analyses, which describe the increase in QALYs or decrease in DALYs per dollar allocated for risk reduction (Weinstein & Stason 1977). In addition to measures of change in DALYs or QALYs due to an intervention,

information about the cost of the public health intervention (the numerator) is needed for these calculations. A criterion used in cost-effectiveness analyses is cost per QALY gained; for example, an intervention that costs \$30,000 per QALY gained is preferred (in general) to one that costs \$60,000 per QALY gained. The Office of Management and Budget (OMB) is evaluating the applicability of such measures in US environmental health decisions (US OMB 2002).

Summary measures of population health are useful burden measures because they combine disparate morbid states (associated with different levels of intensity) and premature mortality into a single composite measure that reflects individual or population preferences for avoiding such outcomes. The relatively large numbers of diseases and health conditions that have been evaluated to date encourages comparisons of disease impacts (Murray & Lopez 1996; WHO 2005). The usefulness of QALYs and DALYs for analyzing disease burden depends on the following:

- accurate disease occurrence data
- sufficient understanding of the impacts of a disease including its duration



Adapted from Gold *et al.* (1996)

Figure 3 | Comparing QALYs and DALYs for a hypothetical lifespan.

- ability of the utility weights to accurately reflect societal preferences for avoiding the disease and its consequences.

The integration of different outcomes into a composite, preference-based measure provides decision-makers with a clear and consistent approach for addressing disease burden.

In the example depicted in [Figure 1](#), IT and CC were both identified as deficiencies that could result in drinking water outbreaks. If QALY or DALY measures were used instead of the epidemiologic measures, the result would be a uni-dimensional analysis of the burden associated with the two deficiencies. For example, the QALYs lost for each person-day ill and each day spent hospitalized would be summed. The total QALYs predicted to be potentially lost through an outbreak associated with IT and through an outbreak associated with CC could then be compared. A decision-maker could decide whether to change treatment practice or improve the distribution system based on the estimates of QALYs lost. A similar example could be developed based on DALYs gained. The information about the QALYs lost (or DALYs gained) uses an explicit trade-off between the different health outcomes caused by the different deficiencies. This information can help answer which of these two deficiencies results in outbreaks having the larger public health impact. Comparisons of the cost-effectiveness of changing treatment practice or improving the distribution system may also be desired. Changes or improvements associated with low cost per QALY gained would be preferred to those with high cost per QALY gained.

QALYs and DALYs account for morbid states that include decreases in mobility, self-care, participation in usual activities, pain and discomfort, anxiety and depression, and cognitive impairment⁶. These composite measures do not capture other factors such as lost wages that result from missing work due to an illness or costs of medical treatment. There are also concerns regarding the approaches used to generate utility weights including whether the individuals who are subject to elicitation

adequately understand the trade-offs they are making in the elicitation (e.g. see concerns identified by [Corso *et al.* 2001](#)).

MONETARY MEASURES

Analysts can also use monetary measures to evaluate disease burden. Although both cost of illness (COI) and willingness to pay (WTP) capture the burden as a monetary estimate (e.g. in terms of dollars), these measures capture different aspects of the burden as described in the next two sections.

Cost of illness

COI approaches are based on costs incurred from contracting a disease ([Rice 1966, 1992](#); [US EPA 1999, 2000, 2002](#); [Drummond *et al.* 1997](#)). These approaches are based on a human capital perspective that focuses on productivity losses and incurred expenses. These costs are measured after the illness or disease has occurred. In this approach, costs are divided into two broad categories: direct costs, which include the market value estimates of treatment, and indirect costs, which include the productivity lost due to morbidity and premature mortality. COI approaches provide information on the monetary impact of an outbreak. Both [Harrington *et al.* \(1991\)](#) and [Corso *et al.* \(2003\)](#) have developed COI estimates for community drinking water outbreaks in the United States, and [Hellard *et al.* \(2004\)](#) used a COI approach to estimate the burden of gastroenteritis in Australia. These studies included evaluations of costs of physician, hospital and emergency room visits, medications and lost work time in their estimate. While this measure of some components of disease burden can provide important insights into the severity of an outbreak, COI measures do not capture all components of an illness that individuals may prefer to avoid ([Kuchler & Golan 1999](#)). For example, COI cannot measure individual preferences for avoiding pain and suffering associated with an illness.

Willingness to pay measures

WTP measures evaluate changes to an individual's level of satisfaction, which is measured by examining the trades of products or services she/he accepts or rejects ([Jones-Lee](#)

⁶ QALYs and DALYs evaluate degrees of morbidity. Asymptomatic infections (infections that an individual was unaware he had contracted) would likely result in no change in an individual's quality of life. These asymptomatic infections may result in additional cases of population illness (e.g. through secondary spread), which would change population DALY or QALY estimates. However, changes in numbers of asymptomatic infections would not change population DALY or QALY estimates.

1976; US EPA 2000; Hammitt 2002). WTP approaches are used to measure an individual's trade-off between a health risk and paying money to reduce such a risk, prior to the trade occurring⁷ (Freeman 1993; Hammitt 2002). In estimating their WTP, individuals likely incorporate perceived medical costs and lost wages due to productivity losses as well as pain and suffering. Individuals also consider their income and age in these evaluations; individuals may increase their WTP to avoid a certain illness with increases in income. Finally, a set of WTP measures for different illnesses will reflect an individual's preferences for avoiding certain illnesses more than others.

The value of a statistical life (VSL) is an aggregate measure of individual WTP to avoid a small change in the risk of dying (Hammitt 2000; US EPA 2000). To estimate the VSL, individuals may be asked if they would be willing to pay some specified amount to reduce the risk of a premature death by a specified probability (e.g. a certain intervention might reduce the probability of death by 1 in 10,000). Suppose 10,000 individuals are willing to pay \$300 each for an intervention that would reduce the risk of dying by 1 in 10,000. The VSL for this group would equal \$3,000,000 for one less death per year. If 10,000 individuals were willing to pay \$300 for an intervention that would reduce the risk of dying by 2 in 10,000, then the VSL would be \$1.5 million (i.e. \$3 million divided by 2). Essentially, the VSL is used to represent the benefit of saving one generic life (rather than an identified individual) from premature mortality (see Hammitt (2002) for a theoretical discussion). Among the uncertainties and limitations of the VSL (NOAA 1993; Viscusi 1993; Viscusi & Aldy 2003), an important concern is whether the subjects adequately understand the risk of death incurred.

WTP approaches are consistent with conventional economic theory (see Freeman 1993; Kuchler & Golan 1999). Conventional economic theory assumes that an individual's choices maximize his well-being (or satisfaction) subject to constraints such as time and money, and individuals act with self-interest using all available information (Freeman 1993; Krupnick *et al.* 1992). Because WTP involves the consideration of avoiding the disease outcome

prior to its occurrence, it implicitly includes values for pain and suffering, medical and non-medical costs (e.g. expenditures for preventative measures and travel time), lost wages due to the disease, lost leisure time and premature death (US EPA 1999, 2002). Although COI measures are sometimes used as a proxy for WTP and sometimes considered a lower bound estimate of WTP (US EPA 2000), COI analyses are limited to the actual costs (e.g. medical costs, lost productivity at home and work) incurred by individuals and society and, as such, do not capture consequences of an illness in the way that WTP measures do.

Use of monetary measures in economic analyses

Benefit-cost analyses examine whether the benefits of an action or intervention exceed costs. These analyses often incorporate WTP and COI (as a proxy of WTP) measures. If the benefits of a public health intervention exceed its costs, then, theoretically, those that benefit from the intervention could compensate those who do not. While this is considered potential compensation, it results in a net social benefit⁸. A net social benefit suggests that the proposed public health intervention makes society better or that the investment is worthwhile. However, it does not consider who potentially benefits or loses from the intervention. Decision-makers may, therefore, examine other aspects of an intervention, such as which subgroups benefit most from an intervention and which bear the largest share of the cost (i.e. the distribution of the benefits and costs).

Returning to the example illustrated in Figure 1, monetary measures also can provide a uni-dimensional measure of the burden (based on dollars) associated with the two deficiencies, IT and CC. For example, the COI associated with each person-day ill and each day spent hospitalized could be summed for both IT and CC and these sums could be compared. The net social benefit of improved treatment practices or improved infrastructure could also be compared.

⁷ Willingness to accept measures are based on the same economic theory as WTP. An individual's willingness to accept is measured by determining how much money one would be willing to accept to incur a small increase in the risk of incurring a health effect (e.g. wage premiums associated with hazardous occupations).

⁸ A criterion used to evaluate the results of benefit-cost analyses is based on the works of Kaldor & Hicks in the late 1930s (see Drummond *et al.* (1997) for a complete discussion). From the perspective of this criterion, a change in societal welfare is an improvement if those who gain from the change could, in principle, fully compensate those who lose, with (at least) one gainer still being better off (i.e. total social benefits exceed total social costs). The objective of a policy analysis is to determine which policy or intervention maximizes the difference between benefits and costs (net benefits).

SUMMARY AND CONCLUSION

Future national estimates of waterborne disease attributable to drinking water could benefit from including burden measures depending on the intended purpose. If the purpose is limited to analyses of waterborne diseases, then there may be limited advantages to developing such an estimate, depending on whether there is a difference in the distribution of symptom severity across different causes of waterborne disease. If the purpose is to broadly compare the impacts of U.S. waterborne disease cases with other diseases or to conduct cost-effectiveness or benefit–cost analyses, then the future estimates should include measures of the disease burden. Burden measures can provide important additional insight into the disease or diseases being evaluated; in particular, they are useful in assessing the impacts of diseases with different symptoms that result in different limitations for an individual's ability to function. Ultimately, whether to develop a burden estimate for waterborne disease attributable to drinking water and the type of burden measure to employ will depend on the needs of the decision-maker.

To develop a burden measure, a complete understanding of the strengths and weaknesses of the epidemiologic data is required. Because the uncertainties in these data will be propagated through the burden analysis, efforts to quantify their impact on the number of cases estimated are a critical component of the burden analysis. An undertaking such as the national estimate is both a useful and a necessary initial step for assessing disease burden.

The epidemiologic measures of symptom severity collected in the studies that are used to develop the national estimate may provide useful burden measures, depending on the needs of the decision-maker. Because epidemiologic data generally form the basis of the information needed for valuation, other data such as the age distribution of illnesses, the range of the symptom duration, the types of medical treatment sought, and the impacts of GI illnesses and other diseases on the afflicted (e.g. ability to work productively, attend school, perform household tasks) need to be identified. Collection of such data would improve COI estimates and provide useful data for future WTP studies of GI illnesses or other diseases.

Summary measures of population health and WTP measures rely on valuation data based on social science

methods. Because disease outcomes may vary, applications of values derived from other countries to the United States are imperfect and uncertain. For example, the utility weights developed for the DALY estimates in Prüss *et al.* (2002) for their global measure of waterborne disease burden may not be applicable to cases of disease in the United States. Thus, waterborne disease research is needed to estimate individuals' preferences in order to calculate appropriate utility weights for summary population health measures or WTP measures for avoiding a distribution of GI symptoms (similar research is needed to facilitate comparisons with other diseases of concern to public health officials). This research should be undertaken prior to including burden measures in future national estimates of waterborne disease attributable to drinking water in the United States.

GLOSSARY

Age-specific death rate Death-rate tabulated according to specific ages or categories of ages (e.g. death rate of individuals above age 70 per year).

Benefit-cost analysis A type of economic analysis in which all costs and benefits are valued in monetary terms and results are expressed as either the net social benefit or the ratio of benefits to cost.

Conventional economic theory The collection of premises that attempt to describe the allocation of resources among consumptive uses, given consumer preferences, societal restrictions or regulations, and environmental constraints. This theory focuses on the maximization of utility or satisfaction level.

Cost-effectiveness analysis (CEA) A type of economic analysis in which costs are valued in monetary terms and health benefits are valued in epidemiologic units. These analyses compare alternative medical treatments or public health strategies.

Cost-of-illness (COI) method An approach to estimate the impacts of a disease by examining two types of costs incurred by an ill person: the direct medical and non-medical costs associated with the illness and the indirect costs associated with lost productivity due to morbidity or premature mortality:

- Direct costs – the measure of the resources expended for prevention activities or health care (compare with indirect cost).
 - *Direct medical costs* The measure of the resources for medical treatment (e.g. the cost of a physician visit).
 - *Direct non-medical costs* Those costs incurred in connection with a health intervention or illness, but which are not expended for medical care itself (e.g. the transportation costs associated with a physician visit).
- Indirect costs – the resources forgone either to participate in an intervention, as the result of an injury or illness (e.g. earnings forgone because of loss of time from work), or to provide care to an ill individual.

Cost-utility analysis (CUA) A subset of cost-effectiveness analysis in which costs are valued in monetary terms and health benefits are expressed as summary population health measures (e.g. DALYs and QALYs). Medical decision-makers rely on cost-utility analyses to compare alternative medical treatments.

Crude death rate The total number of deaths in a population during a specified time divided by the average population size during a specified time (e.g. deaths per 1,000 population per year).

Disability adjusted life years (DALY) A summary public health measure that was developed for the Global Burden of Disease Study. For an illness, a DALY is measured by summing the quantity of life lost due to premature death and the quantity of time lived with a disability due to a disease. The quantity of life lost due to the illness can be calculated by subtracting the age at which a death occurs from the standard life expectancy for the population. The quantity of time lived with a disability is computed as the product of the utility weight (defined below) for the health condition (for DALYs this is normally referred to as a disability weight) and the length of time lived with the disability. Some applications of DALYs employ an age weighting factor. DALYs are frequently used in cost-utility analyses (defined above).

Outbreak Two or more cases of illness that occur following a common exposure.

Person-days ill A quantity describing the length of time individuals in an epidemiologic study are ill with the disease

of interest. For example, a person that is sick for one day would contribute one person-day ill towards the disease incidence measure.

Quality adjusted life years (QALY) A summary public health measure that incorporates the quality or desirability of a health state with the duration of survival. For each health state that an individual experiences, a utility weight (defined below) is assigned. The length of time lived with a specific condition and the utility weight are multiplied. For each condition experienced during a lifetime, these products are summed to estimate the quality adjusted life years that an individual experiences. QALYs are frequently used in cost-utility analyses.

Utility An economic concept that describes an individual's perception of satisfaction for one outcome over another.

Utility weight The numeric value assigned to an impact (value of a health state). This is a quantitative measure that indicates the relative strength of an individual's preference for one outcome over another. In public health, utility suggests the relative desirability of a particular health outcome or health state. These preferences are based on elicited values of a rater (typically a patient or a member of the general public) for that outcome relative to some defined health alternatives.

Willingness to pay (WTP) In the context of this paper, it is a measure of the value an individual places on reducing the risk of some event (e.g. death or illness). It is estimated as the maximum dollar amount an individual would pay preceding a given risk-reducing situation.

Years lived with disability (YLD) The product of the duration of the disease and a disability weight.

Years of life lost (YLL) The number of years of life lost due to a disease or injury. This is an indicator of premature mortality and represents the total number of years *not* lived by an individual dying before a specified age. This is computed by subtracting the age of death due to disease or injury from the mean age of death for a population or the standard life expectancy.

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DISCLAIMER

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