

## 6. CASE STUDY

This case study illustrates the use of cost-effectiveness analysis (CEA) to evaluate alternative drinking water disinfection technologies. The case study evaluates two supplemental disinfection technologies designed to augment a baseline technology of coagulation, sedimentation, sand filtration and chlorine disinfection. The first supplemental technology augments the baseline by adding ozone pretreatment to the coagulation phase of the treatment train. The second supplemental technology consists of the installation of in-home filters in the dwellings of individuals with AIDS.

The case study considers a population served by a single hypothetical treatment plant. The size of the plant (a maximum capacity of 130 million gallons per day (MGD) and an operating capacity of approximately 90 MGD) corresponds to a mid-sized metropolitan area with a population of approximately one-half million people. The case study addresses only conditions in which the technologies (treatment plants or in-home filters) are performing as designed. For example, this case study does *not* evaluate the value of preventing health effects associated with abnormal situations, such as the failure that gave rise to the *Cryptosporidium* outbreak in Milwaukee, WI in 1993. However, the case study's methodology could be extended to address such scenarios given adequate specification of their probability, duration, and their impact on drinking water quality.

Pathogens considered in this analysis are limited to *Cryptosporidium* since, as explained in Section 5.1., the technologies evaluated are not thought to have a differential impact on the concentrations of other infectious agents. Moreover, *Cryptosporidium* oocysts are more likely to

pass through routine treatment because they are small and because they are relatively resistant to chlorine disinfection. The health effects of this pathogen are also relatively severe, especially among immunocompromised individuals. Other health effects considered are cancer, reproductive toxicity, and developmental toxicity, all three of which may be associated with exposure to disinfection by-products (DBPs). Both supplemental technologies considered here are assumed to decrease risks associated with the ingestion of waterborne pathogens. Ozone pretreatment is also thought to decrease the concentration of many DBPs.

The remainder of the case study has five sections. Section 6.1 discusses the use of Monte Carlo analysis to address uncertainty and variability. Section 6.2 describes the computation of the health costs associated with exposure to drinking water. Section 6.3 describes the computation of technology costs. Section 6.4 describes the computation of the cost-effectiveness ratio. Finally, Section 6.5 describes the results of the case study.

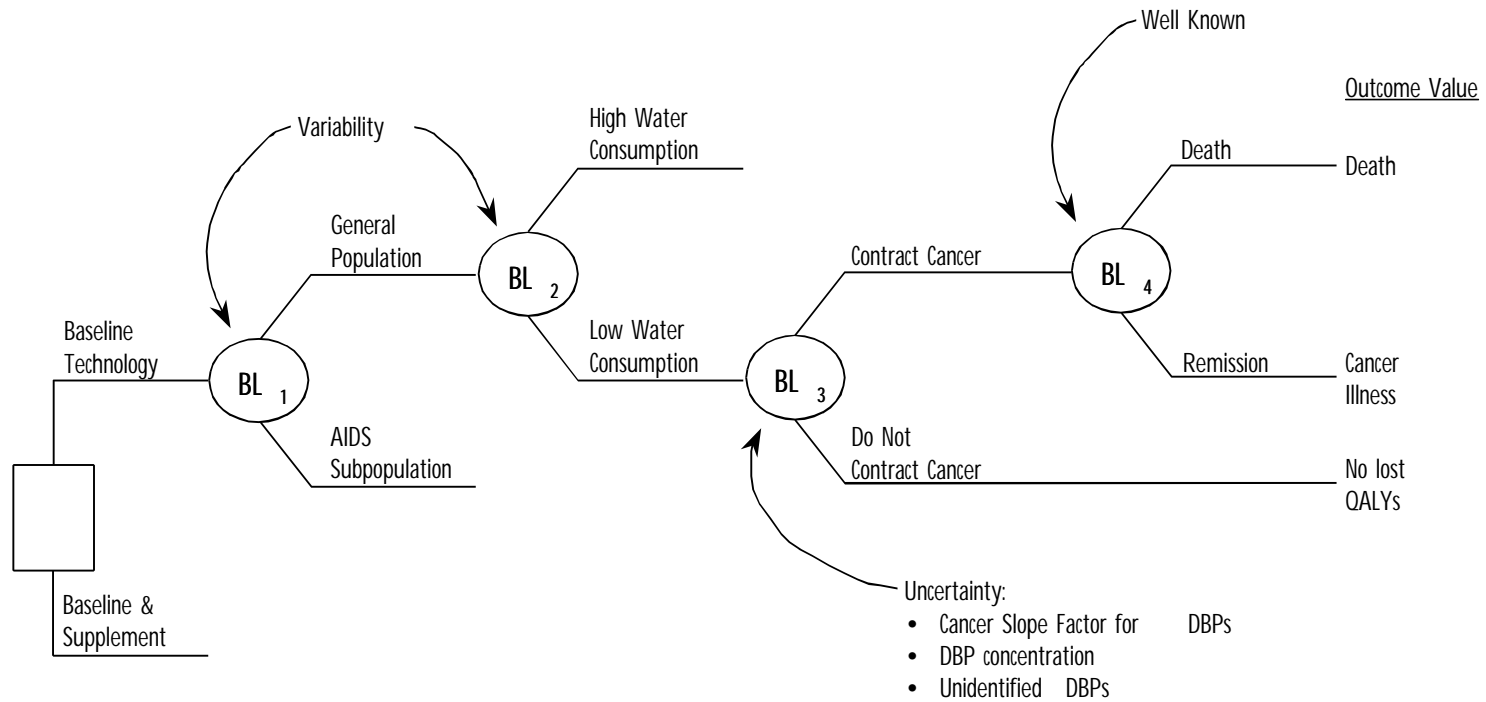
## **6.1. UNCERTAINTY AND VARIABILITY**

The case study uses probabilistic techniques, implemented using Monte Carlo analysis<sup>1</sup>, to address uncertainty and variability. The illustrative decision tree depicted in Figure 6-1 describes the influence of uncertainty and variability on the computation of QALY costs associated with two alternative drinking water treatment options. Note that this illustration

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<sup>1</sup> The simulation was run on an IBM-compatible 233 MHz personal computer. The simulation software was written in SAS version 6.12 (SAS, 1990); the code appears in Appendix B. For the assessment of the ozone pretreatment technology, there were 4 1,000 iteration simulations: 1 for the general population assuming a discount rate of 3%; 1 for the AIDS subpopulation assuming a 3% discount rate, 1 for the general population assuming a 5% discount rate; and 1 for the AIDS subpopulation assuming a 5% discount rate. Two 1,000 iteration simulations were executed to assess the home filter technology's cost effectiveness ratio – one assuming a 3% discount rate, and one assuming a 5% discount rate. In addition to these simulations, two additional simulations have been executed to determine per capita event counts and QALY costs for ozone pretreatment and the baseline treatment technology for individuals whose tap water consumption rates equal the 50th and 90th percentiles for the general population.

Figure 6-1  
Illustrative Decision Tree: Cancer Health Effect



reflects the QALY costs for only a single health endpoint, cancer. Refer to Section 4.8.4. for a preliminary discussion of uncertainty, variability, and the development of decision trees.

The open box at the left side of Figure 6-1 is a choice node representing the choice between the baseline technology alone (upper branch), and the baseline technology plus supplemental technology (lower branch). The open circles are referred to as chance nodes. They represent the possibility of several alternative outcomes, each represented by a branch emanating to the right of the node.

- Chance node  $BL_1$ , the first chance node encountered on the upper branch emanating from the choice node, has two branches representing two possibilities: an individual belongs to the general population or the AIDS subpopulation. This chance node represents variability in the population (specifically, differences in immune status). The probability associated with each branch depends on the prevalence of AIDS in the total population. Although the case study assumes that AIDS status does not influence susceptibility to DBP-induced cancer, AIDS status does influence susceptibility to microbe-induced morbidity and mortality.
- Chance node  $BL_2$  has two outcomes – high water consumption or low water consumption. These two outcomes represent variability in the population and hence the probabilities associated with each branch reflect the frequency of each characteristic in the total population.
- Chance node  $BL_3$  has two outcomes – the development of cancer, or living without cancer. The latter outcome (represented by the bottom branch) terminates in a final outcome which has a value of 0 – i.e., no lost QALYs. The probabilities associated with these outcomes are uncertain because the cancer slope factors for DBPs are not known precisely, DBP concentrations are not known precisely, and because there are unidentified DBPs in drinking water.
- One proceeds to chance node  $BL_4$  if cancer develops. This chance node has two outcomes: death and remission. Each of these outcomes has a negative QALY value. In the context of this case study, the probabilities for these alternative outcomes are assumed to be well-known because it is assumed that DBP carcinogenicity is manifest as cancer of the bladder, colon, or rectum, and because extensive epidemiological data precisely document incidence and fatality rates for these forms of cancer. In reality, the probabilities for each branch emanating from the  $BL_4$  node are uncertain because the types of cancer (if any) caused by DBP exposure are not well-understood.

For each technology, the total QALY cost is the sum of the expected costs for each tree path associated with that technology. The tree paths associated with a technology are those proceeding to the right from that technology's choice branch. The expected value of each path is the product of the probabilities for each branch in the path, and the path's QALY weight, which appears at the path's right terminus.

Additional trees, analogous to the tree depicted in Figure 6-1 for cancer, can be constructed for the other health endpoints. It is important to note that other sources of uncertainty influence the probabilities assigned to the various branches of these other trees (e.g., for *Cryptosporidium* morbidity and mortality, sources of uncertainty include: *Cryptosporidium* source water concentrations, the fraction of *Cryptosporidium* cysts removed by treatment, characteristics of the *Cryptosporidium* dose-response relationship, and so forth). As noted above, AIDS status is an important source of variability in susceptibility in the case of microbial health risks, while it is assumed not to be an important source of variability in the case of DBP-induced health risks. Finally, note that Figure 6-1 is highly simplified. In reality, the outcomes must be divided into more categories to reflect, for example, the age at which cancer is contracted.

As suggested by the preceding discussion, parameters can have multiple possible values for any of three reasons. First, a parameter's true value may be uncertain (but not variable). In this case, the parameter has one true value for all members of the population but that value is not known. In the context of this case study, the following parameters are treated as uncertain:

- The societal discount rate
- Parameters related to *Cryptosporidium*
  - The average annual source water concentration

- The oocyst removal efficiency for the baseline and supplemental technologies
- Parameters related to DBP-induced health effects
  - The DBP slop factors
  - The concentration of DBPs in water after treatment by either technology
- Value parameters
  - The QALY costs associated with various health effects

Second, a parameter may be assumed to vary among members of the population but not be considered to be uncertain<sup>2</sup>. For the case study, the following parameters fall into this category.

- Tap water ingestion rates
  - Total quantity ingested - varies among all members of the population
  - Quantity of unheated tap water ingested - differs among members of the general population, and differs between the general population and AIDS subpopulation

Third, a parameter may be assumed to vary among members of the population *and* to be uncertain. The following parameters, all of which are related to *Cryptosporidium*, fall into this category.

- The infectivity parameter - differs depending on AIDS status
- The conditional probability of illness and death following *Cryptosporidium* infection - differs depending on AIDS status

This case study uses Monte Carlo analysis to independently quantify the impact of uncertainty and variability on the cost-effectiveness ratio for either supplemental technology.

Specifically, the case study assigns fixed values to parameters subject to variability. It then

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<sup>2</sup> Although no parameter has values known with complete certainty, those whose uncertainty is small (e.g., because they can be easily measured empirically) can be treated as known. Explicit characterization of their uncertainty would not substantially affect the analysis because this uncertainty would be “swamped” by the much greater uncertainty of other parameters.

repeatedly calculates the expected QALY cost of each technology 1,000 times, each time basing the calculation on randomly drawn values for each of the uncertain parameters. These uncertain parameter values are drawn from probability distributions that represent the relative plausibility of alternative possibilities. The results from a large number of such computations quantify the impact of uncertainty since the result represents the range of plausible cost effectiveness ratios for members of society described by the fixed values assigned to the variable parameters for that simulation.

For the ozone pretreatment technology, a separate analysis has been conducted for each of the following societal subgroups:

- The entire general population<sup>3</sup>
- Members of the general population whose water consumption rate is equal to the median ingestion rate;
- Members of the population whose water consumption rate is equal to the 90th percentile ingestion rate;
- Members of the AIDS subpopulation.

Differences between the results for these simulations reflect the influence of variability.

Finally, the results from a Monte Carlo analysis can be used not only to quantify the influence of uncertainty and variability, but also to identify which uncertain assumptions have the greatest influence on the computation. To do so, the analysis records the value assigned to each

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<sup>3</sup> The entire general population is represented by setting tap water ingestion rates to their arithmetic average for the general population. This approach works because the DBP-induced risks (and hence QALY costs) are a linear function of consumption and microbial risks (and hence QALY costs) are almost exactly a linear function of consumption. As a result, the denominator of the cost effectiveness ratio (QALY costs) for an individual whose tap water consumption rate equals the arithmetic average for the population is equal to the per capita QALY costs averaged over the population.

uncertain parameter, along with the corresponding computed cost-effectiveness ratio value. Table 6-1 describes the type of results produced.

These results represent  $n$  calculations. For calculation  $i$ , the  $j$ th uncertain parameter is assigned value  $V_{ij}$ , while the calculated cost-effectiveness ratio for calculation  $i$  is  $CE_i$ . Using ordinary least squares regression, the analysis regresses the column of CE values against the matrix of uncertain parameter values. Doing so quantifies the fraction of (linear) variation in the cost-effectiveness ratio attributable to each uncertain parameter. This procedure is similar to that described by Cohen et al. (1996).

Note that this procedure is a heuristic for quantifying the degree to which each parameter's uncertainty explains the cost-effectiveness ratio's *linear* variation. Since not all the variation is linear, the total explained variation is less than 100%. Moreover, it is not the purpose of this analysis to fully characterize variation in the cost-effectiveness ratio. Doing so is theoretically possible since the cost-effectiveness ratio is computed using the parameter values selected by the simulation. However, it is likely that a fully explanatory model would be very complex, making it difficult to intuitively grasp the influence of each parameter.

## **6.2. COMPUTATION OF QALY COSTS**

This section describes the computation of a drinking water treatment technology's QALY cost, which is the value (in QALYs) placed on avoiding all health events caused by exposure to DBPs and pathogens in drinking water during the analytical time frame for the analysis of



**TABLE 6-1****Illustration of the use of Monte Carlo Techniques to Conduct Sensitivity Analysis**

Simulation	Uncertain Parameters				Calculated CE Ratio
	P1	P2	P3	P4	
1	V <sub>11</sub>	V <sub>12</sub>	V <sub>13</sub>	V <sub>14</sub>	CE <sub>1</sub>
2	V <sub>21</sub>	V <sub>22</sub>	V <sub>23</sub>	V <sub>24</sub>	CE <sub>2</sub>
...					CE <sub>3</sub>
n	V <sub>n1</sub>	V <sub>n2</sub>	V <sub>n3</sub>	V <sub>n4</sub>	CE <sub>4</sub>

20 years<sup>4</sup>. Conceptually, this cost is the product of two components: the number of health events caused (which corresponds to “risk”), and the value placed on avoiding each of those events (which corresponds to “severity”). The case study computes a technology’s QALY cost by dividing all potential health events into groups consisting of events that all have the same cost. Specifically, the case study multiplies the number of events in each of these groups by each group’s per-event cost, and then sums the results over all the groups. The following discussion describes how these groups are defined.

A health event’s cost depends first on the health endpoint, which can be any of the DBP-induced effects, *Cryptosporidium*-induced morbidity, or *Cryptosporidium*-induced mortality. The technology’s QALY cost is therefore computed as the sum of the costs attributable to events of each endpoint type.

The second factor determining an event’s cost is how far in the future it occurs. Because of discounting (see Section 4.8.2.), health events that occur further in the future have a smaller

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<sup>4</sup> A more complete analysis would use an analytical time frame that matches the estimated life of each technology evaluated. This duration may be longer than 20 years in the case of a treatment plant and somewhat less than that for in-home filters.

cost, all else being equal. When the event occurs depends on 1) when the exposure causing that event takes place, and 2) the duration between that exposure and the manifestation of the illness, a period referred to as the event's latency. To account for the delay until exposure, the case study divides the events for each endpoint type into 20 groups, each corresponding to 1 of the 20 years of the analytical time frame. The first group consists of events caused by exposure to drinking water during the first year of the analytical time frame, the second consists of events caused by exposure to drinking water during the second year of this time frame, and so forth.

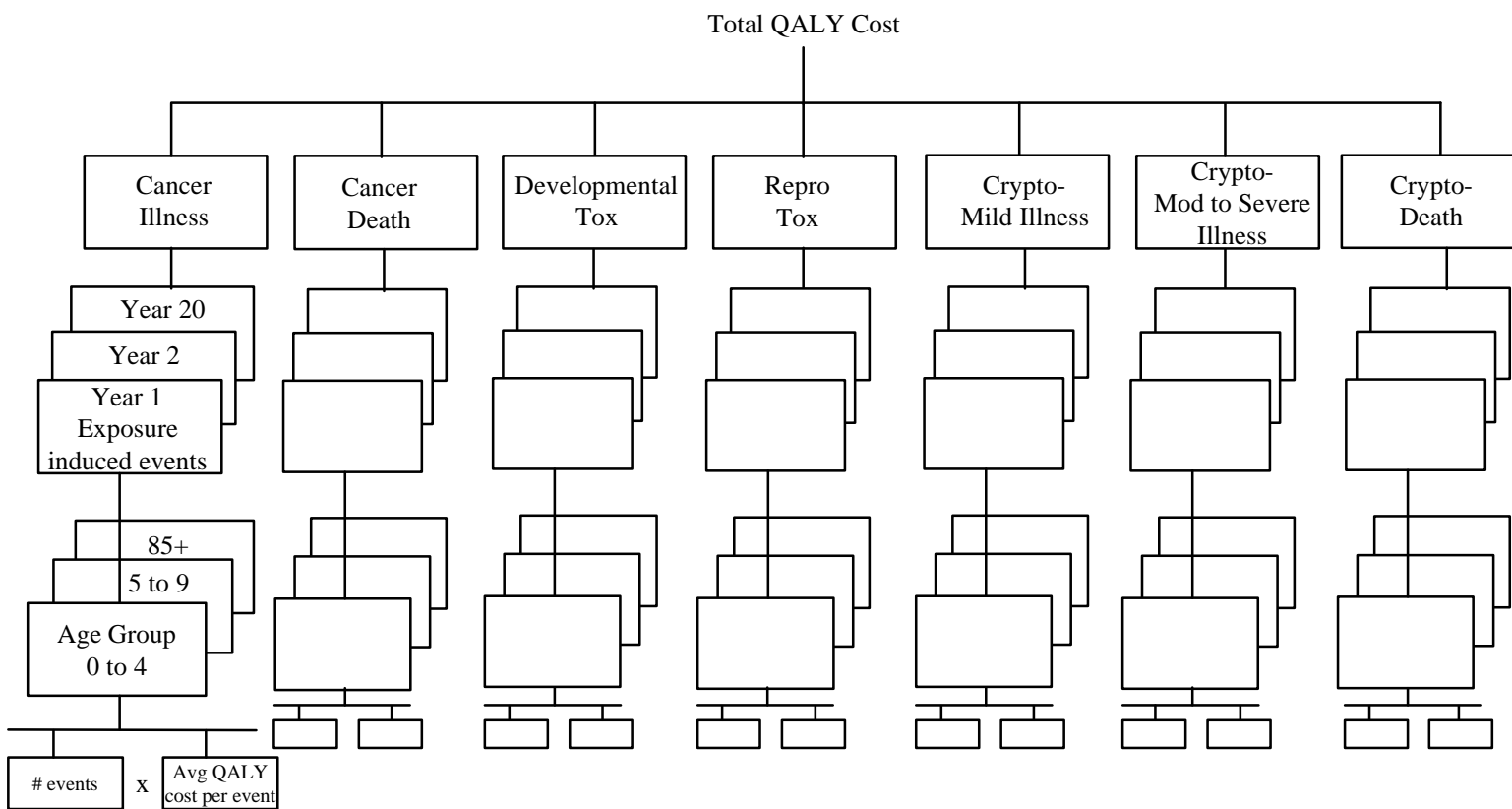
Because the latency period can depend on the age at which exposure occurs,<sup>5</sup> events caused by exposure during a single year of the analytical time frame are further subdivided into 18 groups, each corresponding to a 5-year age cohort (ages 0 to 4, 5 to 9, and so forth, up to ages 80 to 84, and 85 and above). Considering each age cohort separately also facilitates computation of the number of events caused by drinking water exposure because a health event's probability can depend on the age at which exposure occurs. For example, because the case study assumes that the risk of DBP-induced reproductive toxicity depends only on current exposure, individuals not in their childbearing years are at no risk for reproductive toxicity.

Figure 6-2 illustrates the division of drinking water-induced health events by endpoint type, year of responsible exposure, and age at exposure. Within each event type / exposure year /age cohort grouping, the number of events is the product of the number of individuals in that age cohort and the number of events per individual in that age cohort. The average QALY cost of each such event depends on 1) the QALY cost that would be assigned to the event without any latency period, 2) the range of and relative likelihood of different latency periods,

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<sup>5</sup> As described in Section 6.2.2.4, the latency period for cancer, as computed in this case study, depends on the age at which the exposure causing the cancer occurs.

Figure 6-2  
Computation of a Treatment Plant's QALY Costs



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and 3) the fraction of individuals who will still be alive after latency periods of various durations. A high probability of a long latency period, as in the case of cancer among individuals exposed at a young age, means that the average estimated QALY cost of the health endpoint must be depressed to reflect discounting. If there is a high probability that members of a cohort will not survive the duration of the latency period (e.g., among members of the AIDS subpopulation), the cost of the health event must be depressed further.

The remainder of Section 6.2 has three parts. Section 6.2.1 describes the computation of a technology's QALY cost in greater detail. Section 6.2.2 details the equations comprising this computation, along with the values for the parameters in those equations.

**6.2.1. Computation of a Technology's QALY Cost: Description.** A technology's total QALY cost over its 20 year productive lifetime (denoted TCost) is the sum of the QALY costs attributable to each of the 7 health endpoints (denoted HECost<sub>*i*</sub>, where *i* ranges from 1 to 7) considered in this case study:

- Cancer illness;
- Cancer death;
- Birth defects resulting from developmental toxicity;
- Infertility resulting from reproductive toxicity (defined to be an inability to conceive);
- Mild illness resulting from *Cryptosporidium* infection;
- Moderate to severe illness resulting from *Cryptosporidium* infection; and
- Death resulting from *Cryptosporidium* infection.

The cost for each health endpoint over the analytical time frame of 20 years is the sum of the costs resulting from each year of exposure. Specifically,

$$HECost_i = YCost_{i,1} + YCost_{i,2} + \Lambda + YCost_{i,20} \quad (6-1)$$

where  $YCost_{i,j}$  is the cost of health events of type  $i$  caused by drinking water exposure during year  $j$  of the analytical time frame.

The cost attributable to exposure during year  $j$  of the analytical time frame is the sum of the costs incurred by each age group in the population. The calculation employed for this case study divides the population into 18 age groups: ages 0 to 4, 5 to 9, and so forth, through ages 80 to 84, and ages 85 and above. Specifically, the QALY cost of health events of type  $i$  resulting from exposure during year  $j$  of the analytical time frame ( $YCost_{i,j}$ ) is

$$YCost_{i,j} = YCost_{i,j}(AG\ 0to4) + YCost_{i,j}(AG\ 5to9) + \Lambda + YCost_{i,j}(AG85+) \quad (6-2),$$

where  $YCost_{i,j}(AG\ a\ to\ b)$  is the QALY cost of health events of type  $i$  resulting from exposure during year  $j$  of the analytical time frame among individuals between the ages of  $a$  and  $b$  (inclusive) at the time of exposure.

The value of  $YCost_{i,j}(AG\ a\ to\ b)$  is the product of two factors:

- The incremental number of health events of type  $i$  expected among individuals between the ages of  $a$  and  $b$  (inclusive) resulting from exposure to drinking water among this cohort during year  $j$  of the analytical time frame; and
- The average QALY value of each such health event.

The incremental number of health events is the product of

- The incremental risk of contracting the health effect each time an individual in this age cohort is “at risk” for developing the condition;
- The average number of times each member of the cohort is at risk for the condition
- The number of individuals in the population belonging to this age cohort.

The average QALY cost of each health event depends on:

- How far into the future the event takes place (event latency); and
- The fraction of individuals in the age cohort who remain alive at the end of the latency period.

The average value of all these health events is the sum of the fraction occurring after each potential latency period multiplied by the net present value of the event and fraction of individuals in the age cohort still alive after that latency.

### **6.2.2. Computation of a Technology’s QALY Cost: Equations and Parameter Values.**

The following discussion develops formal equations corresponding to the relationships described in Section 6.2.1. For each parameter, this Section provides values or refers the reader to the appropriate sections in Chapter 5 of this document.

The technology’s total QALY cost (TCost) is the sum of the costs for each of the 7 health effects considered (HECost<sub>i</sub>). These costs are, in turn, the sum of the costs incurred due to exposure during each of the 20 years of the analytical time horizon. Assuming that the population age distribution is relatively stable over this period, and assuming that incremental health effect risks incurred due to exposure in one year do not depend on the risks incurred in previous years, health costs are the same each year, except for the impact of discounting. This constant cost for

health effect  $i$  is designated  $YCost_i$ . Hence, total costs over the 20-year analytical time frame for health effect  $i$  are

$$HECost_i = \frac{1}{(1+d)^{0.5}} \sum_{j=1}^{20} \frac{YCost_i}{(1+d)^{j-1}}, \quad (6-3)$$

where the leading term preceding the summation is a correction reflecting the fact that exposures occur, on average, approximately half way through the year and hence must be discounted by

$$\frac{1}{(1+d)^{0.5}}.$$

From the definition of  $YCost_{i,k}$ , the cost for health effect  $i$  resulting from one year of exposure among members of age cohort  $k$ , it follows that  $YCost_i$  is the sum of the  $YCost_{i,k}$  over all values of  $k$ . Values for the parameter  $k$  range from 1 to 18, where  $k = 1$  represents the cohort from ages 0 to 4,  $k = 2$  represents the cohort from ages 5 to 9, and so forth, through  $k = 18$ , which represents the cohort for ages 85 and above. As noted in Section 6.2.1, the value of  $YCost_{i,k}$  is the expected number of health events of type  $i$  among cohort  $k$  resulting from 1 year of exposure multiplied by the average value of each of those health events. That is,

$$YCost_{i,k} = NumEvents_{i,k} \times AvgQCost_{i,k} \quad (6-4),$$

where,

NumEvents<sub>i,k</sub> = The incremental number of health events of type  $i$  among members of cohort  $k$  due to 1 year of drinking water exposure; and

$AvgQCost_{i,k}$  = The average QALY cost for events of type  $i$  among individuals who belong to cohort  $k$  during the year of the exposure leading to the event.

The value of  $NumEvents_{i,k}$  is

$$NumEvents_{i,k} = \Delta r_{i,k} \times N\_AtRisk_{i,k} \times PopSize_k \quad (6-5)$$

where,

$\Delta r_{i,k}$  = The incremental risk of contracting the health effect each time an individual in this cohort is “at risk” for developing the condition;

$N\_AtRisk_{i,k}$  = The average number of times each member of the cohort is at risk for the condition;

$PopSize_k$  = The number of individuals in the population belonging to age cohort  $k$ .

The value of  $AvgQCost_{i,k}$  is

$$AvgQCost_{i,k} = \sum_{latency\ l=0}^{MaxAge} Pr\ Latency_{i,k,l} \times Pr\ Alive_{k,l} \times \frac{QVal_{i,age(k)+l}}{(1+d)^l} \quad (6-6),$$

where,

$MaxAge$  = The maximum age to which individuals may survive;

$age(k)$  = The midpoint of the age range for age cohort  $k$ ;

$PrLatency_{i,k,l}$  = The probability that the latency period is  $l$  years for an event of type  $i$  resulting from exposure while a member of age cohort  $k$ ;

$PrAlive_{k,l}$  = The probability that a member of cohort  $k$  will still be alive after a latency period of  $l$  years; and



$QVal_{i,age(k)+l}$  = The QALY value of a health event of type  $i$  for an individual whose age is  $l$  years greater than the mean age among members of age cohort  $k$ .

Combining Equations 6-3 through 6-6 yields

$$TCost = \sum_{i=1}^7 \frac{1}{(1+d)^{0.5}} \times \sum_{j=1}^{20} \frac{1}{(1+d)^{j-1}} \times \sum_{k=1}^{18} \Delta r_{i,k} \times N\_AtRisk_{i,k} \times Popsiz_e_k \times \sum_{l=0}^{MaxAge-age(k)} Pr\ Latency_{i,k,l} \times Pr\ Alive_{k,l} \times \frac{QVal_{i,age(k)+l}}{(1+d)^l} \quad (6-7),$$

where,

- $i$  = The index over the 7 health event types considered in this case study;
- $j$  = The index over the 20 years of the analytical time horizon;
- $k$  = The index over 18 age cohorts comprising the population ( $k=1$  corresponds to ages 0 to 4,  $k=2$  corresponds to ages 5 to 9, and so forth, through  $k=18$ , which corresponds to ages 85 and above); and
- $l$  = The duration of the latency period – i.e., the number of years between exposure and the manifestation of the resulting health effect.

The remainder of Section 6.2.2 specifies the values for the parameters in equation 6-7.

**6.2.2.1. The Value of  $\Delta r_{i,k}$**  — In the case of DBP-induced cancer morbidity, infertility, and developmental defects, the value of  $\Delta r_{i,k}$  is a function of the slope factors for each DBP (including unidentified TOX), the concentrations for each of those substances, and the age-specific total tap water ingestion rate in L/kg-day (see Sections 5.2 and 5.3). The value of the incremental risk depends on the disinfection technology because the type of technology used determines tap water DBP concentrations.

For cancer mortality, the value of  $\Delta r_{i,k}$  is assumed to equal the value of  $\Delta r_{i,k}$  for cancer illness multiplied by the probability that an individual who contracts bladder cancer or colon rectal

cancer dies. For the purpose of the case study, it is assumed that the conditional probability of dying among individuals who contract DBP-induced cancer is the lifetime probability of dying from bladder, colon, or rectal cancer for the entire population (3.19%) divided by the lifetime probability of contracting these diseases (9.06%) (see Tables VI-13 and XXVI-8 in Ries et al., 1998). The quotient is 0.35.

Finally, for *Cryptosporidium*-induced morbidity and mortality,  $\Delta r_{i,k}$  is calculated as described in Table 6-2. The values of the parameters in this table are detailed in Section 5.5.

**6.2.2.2. N\_AtRisk** —  $N\_AtRisk_{i,k}$  is the average number of times each individual in cohort  $k$  is at risk for health events of type  $i$  due to a single year of exposure to drinking water. The following discussion explains the value of this parameter for each type of health event.

Cancer morbidity and mortality:  $N\_AtRisk$  is assumed to be 1 for all age cohorts. That is, all members of each age cohort are assumed to be at risk for developing cancer as the result of a single year of drinking water consumption. Moreover, it is assumed that for each individual, exposure to DBPs can cause only a single case of cancer<sup>6</sup>.

Reproductive toxicity: Since reproductive toxicity can manifest itself only among individuals who are attempting to conceive a child,  $N\_AtRisk_{i,k}$  is equal to the proportion of individuals belonging to cohort  $k$  who are attempting to conceive. Since there are no readily available data quantifying this statistic, the case study makes use of birth rates per woman as a proxy for the fraction of women attempting to conceive<sup>7</sup>. Nor are there readily available data

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<sup>6</sup> A relapse is hence characterized as a continuation of the primary case of cancer.

<sup>7</sup> This approximation is reasonable if the fraction of individuals who are infertile is relatively small. For older women, it is likely that this fraction is not small and hence that the use of the birth rate may substantially underestimate the fraction of individuals attempting to conceive.

**TABLE 6-2**  
**Computation of  $\Delta r_{i,k}$  for *Cryptosporidium*-induced Morbidity and Mortality**

<b>The Value of <math>\Delta r</math> for:</b>	<b>Is The Product of the Probability of Infection and:</b>
Mild Illness	The conditional probability of mild illness given infection
Moderate to severe illness	The conditional probability of mild illness given infection, The conditional probability of moderate to severe illness given mild illness
Fatality	The conditional probability of mild illness given infection, The conditional probability of moderate to severe illness given mild illness, The conditional probability of death given moderate to severe illness

quantifying the corresponding statistic for men. The case study therefore uses the birth rate for women as a proxy for males as well as females. Hence,  $N_{AtRisk}$  for the general population is assumed to equal the birth rate among women. Note that for the AIDS subpopulation,  $N_{AtRisk}$  is assumed to be zero since it is assumed that members of this subpopulation do not attempt to conceive children.

Developmental toxicity: Since the case study characterizes the cost of this effect in terms of its impact on the offspring, the fraction of individuals at risk equals the number of live births divided by the size of the population. This value is approximately equal to the live birth rate per member of the population, or approximately one-half the live birth rate per woman. Note that, as in the case of reproductive toxicity, it is assumed  $N_{AtRisk}$  is zero for the AIDS subpopulation.

Microbial illness: It is assumed that an individual can become ill once every 12 weeks, or 4.33 times per year. This assumption is consistent with Hurst et al. (1996), who note that

(p. 117), “*It is possible for reinfection to occur as soon as 12 weeks after initial infection.*”

Hence, each member of every cohort is at risk of becoming infected and hence ill approximately 4.33 times per year ( $12 \text{ weeks} \div 52 \text{ weeks per year}$ ), yielding a value of 4.33 for  $N_{\text{AtRisk}}$ .

Microbial-induced death: Since an individual might die as the result of each case of microbial-induced illness,  $N_{\text{AtRisk}}$  is 4.33 for microbial-induced mortality.

Summary: Table 6-3 summarizes the  $N_{\text{AtRisk}}$  values for all health endpoints considered in the case study.

**6.2.2.3.  $\text{PopSize}_k$**  —  $\text{PopSize}_k$  is the number of individuals in the population belonging to age cohort  $k$ . It is assumed that the general population served by the hypothetical treatment plant that is the subject of this case study has the same age distribution as the U.S. population, while the AIDS subpopulation served by the hypothetical treatment plant has the same age distribution as that of the U.S. AIDS subpopulation. Table 6-4 details the age distribution for the general U.S. population (columns 1 and 3) and for the AIDS subpopulation (columns 2 and 4).

The value of  $\text{PopSize}_k$  for the general population is the product of the appropriate entry in column 3 of Table 6-4 and the size of the general population served by the hypothetical treatment plant that is the subject of this case study. It is assumed that the hypothetical treatment plant has a maximum capacity of 130 million gallons per day (MGD) and an operational capacity of 90 MGD. In 1990, U.S. per capita water consumption from public water supplies amounted to 195 gallons per day (Table 375 in U.S. Bureau of the Census, 1997). Hence, the population served by this hypothetical plant is assumed to number  $90 \text{ MGD} \div (195 \text{ gallons/day-individual})$ , or approximately 460,000 individuals.

TABLE 6-3

## N\_AtRisk for all Health Effects Evaluated

Exposure Age	Cancer Illness	Cancer Death	Reproductive Tox		Developmental Tox		Mild Microbial Illness	Moderate to Severe Microbial Illness	Microbial-induced Death
			Gen. Popul. <sup>a</sup>	AIDS	Gen. Popul. <sup>b</sup>	AIDS			
0 to 4	1	1	0	0	0	0	4.33	4.33	4.33
5 to 9	1	1	0	0	0	0	4.33	4.33	4.33
10 to 14	1	1	0.0012	0	0.0006	0	4.33	4.33	4.33
15 to 19	1	1	0.0554	0	0.0227	0	4.33	4.33	4.33
20 to 24	1	1	0.1104	0	0.0552	0	4.33	4.33	4.33
25 to 29	1	1	0.1131	0	0.0566	0	4.33	4.33	4.33
30 to 34	1	1	0.0839	0	0.0420	0	4.33	4.33	4.33
35 to 39	1	1	0.0353	0	0.0177	0	4.33	4.33	4.33
40 to 44	1	1	0.0068	0	0.0034	0	4.33	4.33	4.33
45 to 49	1	1	0.0003	0	0.0002	0	4.33	4.33	4.33
50 to 54	1	1	0	0	0	0	4.33	4.33	4.33
55 to 59	1	1	0	0	0	0	4.33	4.33	4.33
60 to 64	1	1	0	0	0	0	4.33	4.33	4.33
65 to 69	1	1	0	0	0	0	4.33	4.33	4.33
70 to 74	1	1	0	0	0	0	4.33	4.33	4.33
75 to 79	1	1	0	0	0	0	4.33	4.33	4.33
80 to 85	1	1	0	0	0	0	4.33	4.33	4.33
85+	1	1	0	0	0	0	4.33	4.33	4.33

Notes: Source: Table 3 in Pamuk et al. (1998).

Values are 1/2 the live birth rates referenced in note (a).

**TABLE 6-4**  
**Age Distribution for the United States General Population and AIDS Subpopulation**

Age Range	Number of Individuals in the U.S. Population		Fraction of the U.S. Population	
	General Population <sup>a</sup>	AIDS subpopulation <sup>b</sup>	General Population <sup>a</sup>	AIDS subpopulation <sup>b</sup>
0 to 4	19,286,000	3,194	7.27%	0.59%
5 to 9	19,441,000	611	7.33%	0.11%
10 to 14	18,981,000	919	7.15%	0.17%
15 to 19	18,662,000	1,381	7.03%	0.26%
20 to 24	17,560,000	16,899	6.62%	3.14%
25 to 29	19,007,000	72,317	7.16%	13.42%
30 to 34	21,361,000	123,255	8.05%	22.88%
35 to 39	22,577,000	121,806	8.51%	22.61%
40 to 44	20,816,000	89,491	7.85%	16.61%
45 to 49	18,436,000	51,541	6.95%	9.57%
50 to 54	13,934,000	27,177	5.25%	5.04%
55 to 59	11,362,000	15,042	4.28%	2.79%
60 to 64	9,999,000	8,307	3.77%	1.54%
65 to 69	9,862,500	6,762	3.72%	1.26%
70 to 74	8,778,500	0	3.31%	0.00%
75 to 79	6,873,000	0	2.59%	0.00%
80 to 84	4,557,000	0	1.72%	0.00%
85+	3,761,000	0	1.42%	0.00%
Total	265,284,000	538,702	100%	100%

Notes: Source: Table 22 in U.S. Bureau of the Census (1997).

Source: Table 9 in CDC (1997). Note that this source lists cumulative AIDS cases reported through December, 1997 by age at diagnosis. U.S. EPA is unaware of data listing existing AIDS cases by age. For the purpose of this case study, these data will serve as a surrogate.

For the AIDS subpopulation, the value of  $\text{PopSize}_k$  is the product of the appropriate entry in column 4 of Table 6-4 and the size of the AIDS subpopulation served by the hypothetical treatment plant. It is assumed that the fraction of individuals in the total population with AIDS is equal to the corresponding fraction for the entire U.S. population<sup>8</sup>. In 1997, there were approximately 247,000 individuals living with AIDS in 1997 (Table 33 in CDC, 1997). The population of the United States in 1996 was approximately 265,000,000 (U.S. Bureau of the Census, Table 14). Hence, approximately 93 out of every 100,000 individuals in the population belong to the AIDS subpopulation, or 429 individuals in the total hypothetical population of 460,000 served by the treatment plant that is the subject of this case study.

**6.2.2.4. PrLatency<sub>i,k,l</sub>** — For the purpose of this case study, it is assumed that there is no appreciable delay between exposure and the manifestation of a health effect for microbial morbidity and mortality, for reproductive toxicity, and for developmental toxicity.

Information on the latency period that separates an exposure that leads to disease from the manifestation of disease is limited. For the purpose of this study, it is assumed that cancer caused by DBP carcinogenicity includes urinary bladder cancer, colon cancer, and rectal cancer. The latency period for DBP-induced cancer is assumed to be consistent with the age-specific incidence rate distribution for these cancers for the U.S. population, detailed in Table 6-5.

Hence, the probability that cancer resulting from exposure at age  $\text{age}_k$  (the minimum age for members of age cohort  $k$ ) has a latency period of  $l$  is proportional to the cancer incidence rate at age  $(\text{age}_k + l)$ . More specifically, the probability that a cancer caused by exposure at age  $\text{age}_k$

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<sup>8</sup> The fraction of individuals with AIDS in typical urban areas would be a more appropriate value for this parameter. However, published data quantifying this fraction are not readily available.

**TABLE 6-5**  
**Incidence per 100,000 Individuals for Urinary Bladder Cancer, and Colon**  
**Cancer and Rectum Cancer: By Age<sup>a</sup>**

Age (Years)	Type of Cancer		Total
	Urinary Bladder <sup>b</sup>	Colon and Rectum <sup>c</sup>	
0 to 4	0	0	0
5 to 9	0	0	0
10 to 14	0	0	0
15 to 19	0.2	0.2	0.4
20 to 24	0.3	0.6	0.9
25 to 29	0.5	1.6	2.1
30 to 34	1.1	3.4	4.5
35 to 39	2.1	6.2	8.3
40 to 44	4.1	12.8	16.9
45 to 49	9.1	24.0	33.1
50 to 54	18.2	48.9	67.1
55 to 59	32.8	87.5	120.3
60 to 64	52.7	136.9	189.6
65 to 69	84.9	203.2	288.1
70 to 74	111.3	277.8	389.1
75 to 79	130.5	356.1	486.6
80 to 85	150.0	444.3	594.3
85+	137.8	460.7	598.5

Notes: <sup>a</sup>Data on cancer morbidity and mortality are reported as part of the Surveillance, Epidemiology, and End Results (SEER) Program of the National Cancer Institute (NCI). Tables cited here are from Ries et al. (1998). The SEER program was designed to collect data on cancer occurrence on a routine basis from population-based cancer registries in nine geographic areas around the U.S. which are designed to provide a reasonably representative subset of the U.S. population. Data on cancer mortality reported by the SEER program is obtained from the National Center for Health Statistics and provides greater than 99% complete death registration coverage for the U.S. The denominator data for calculation of incidence and mortality rates by SEER is obtained from the data tapes of the U.S. Census Bureau.

<sup>b</sup>Based on the age-specific rates listed in column 1 of Table XXXVI-2 in Ries et al. (1998).

<sup>c</sup>Based on the age-specific rates listed in column 1 of Table VI-3 in Ries et al. (1998).



is  $l$  years is the incidence rate at age  $(age_k + l)$  divided by the total incidence among individuals at least  $age_k$  years of age.

For example, for the age 0 to 4 cohort, the probability that the latency period for bladder, colon, and rectal cancer combined<sup>9</sup> will be approximately 50 years (i.e., the cancer will develop between ages 50 and 54) is the incidence rate for individuals between the ages of 50 and 54 ( $6.71 \times 10^{-4}$ ) divided by the incidence rate for the entire population of  $2.8 \times 10^{-2}$  (the sum of the values in the far right column of Table 6-5). This quotient is 2.4%. For the age 60 and 64 cohort, the probability that latency period is 10 years is the incidence rate for individuals between the age of 70 and 74 years of age ( $3.89 \times 10^{-3}$ ) divided by the incidence rate for all individuals above the age of 60 ( $2.55 \times 10^{-2}$ ), or 15.3%.

Table 6-6 details the cancer illness latency period probabilities for all exposure ages. Each entry is the probability that a cancer will develop at the age listed at the far left end of that entry's row if it is caused by an exposure at the age listed at the top of that entry's column. For example, for an individual who develops cancer due to exposure at age 5 to 9, there is a 2.40% chance that the cancer will occur between the ages of 50 and 54. Equivalently, a cancer caused by DBP exposure between the ages of 5 and 9 has a 2.40% of having a latency period of 45 years.

The latency period distribution for cancer mortality has been calculated in the same manner as the latency period for cancer illness. Fatality rates for bladder, colon, and rectal cancer per 100,000 individuals in the United States appear in Table 6-7. Each entry in Table 6-8 is the probability that a cancer fatality caused by exposure at the age listed at the head of that entry's column will occur at the age listed at the left end of that entry's row.

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<sup>9</sup> The "combined" latency probabilities have been calculated using the far right column in Table 6-5.

**TABLE 6-6<sup>a,b,c</sup>**  
**Probability of Cancer Occurring at Age at Left End of Row if the Cancer Results from Exposure at Age at Top of Column**

	0 to 4	5 to 9	10 to 14	15 to 19	20 to 24	25 to 29	30 to 34	35 to 39	40 to 44	45 to 49	50 to 54	55 to 59	60 to 64	65 to 69	70 to 74	75 to 79	80 to 84	85+
<b>0 to 4</b>	0.00%																	
<b>5 to 9</b>	0.00%	0.00%																
<b>10 to 14</b>	0.00%	0.00%	0.00%															
<b>15 to 19</b>	0.01%	0.01%	0.01%	0.01%														
<b>20 to 24</b>	0.03%	0.03%	0.03%	0.03%	0.03%													
<b>25 to 29</b>	0.08%	0.08%	0.08%	0.08%	0.08%	0.08%												
<b>30 to 34</b>	0.16%	0.16%	0.16%	0.16%	0.16%	0.16%	0.16%											
<b>35 to 39</b>	0.30%	0.30%	0.30%	0.30%	0.30%	0.30%	0.30%	0.30%										
<b>40 to 44</b>	0.60%	0.60%	0.60%	0.60%	0.60%	0.60%	0.60%	0.61%	0.61%									
<b>45 to 49</b>	1.18%	1.18%	1.18%	1.18%	1.18%	1.18%	1.18%	1.19%	1.19%	1.20%								
<b>50 to 54</b>	2.40%	2.40%	2.40%	2.40%	2.40%	2.40%	2.40%	2.40%	2.41%	2.43%	2.45%							
<b>55 to 59</b>	4.30%	4.30%	4.30%	4.30%	4.30%	4.30%	4.30%	4.31%	4.32%	4.35%	4.40%	4.51%						
<b>60 to 64</b>	6.77%	6.77%	6.77%	6.77%	6.77%	6.78%	6.78%	6.79%	6.81%	6.85%	6.94%	7.11%	7.45%					
<b>65 to 69</b>	10.29%	10.29%	10.29%	10.29%	10.29%	10.30%	10.30%	10.32%	10.35%	10.41%	10.54%	10.81%	11.32%	12.23%				
<b>70 to 74</b>	13.90%	13.90%	13.90%	13.90%	13.90%	13.91%	13.92%	13.94%	13.98%	14.07%	14.24%	14.59%	15.28%	16.51%	18.81%			
<b>75 to 79</b>	17.38%	17.38%	17.38%	17.38%	17.38%	17.39%	17.40%	17.43%	17.48%	17.59%	17.80%	18.25%	19.11%	20.65%	23.53%	28.98%		
<b>80 to 84</b>	21.23%	21.23%	21.23%	21.23%	21.23%	21.24%	21.25%	21.29%	21.35%	21.48%	21.74%	22.29%	23.34%	25.22%	28.74%	35.39%	49.84%	
<b>85+</b>	21.37%	21.37%	21.37%	21.37%	21.37%	21.38%	21.39%	21.43%	21.49%	21.62%	21.89%	22.44%	23.50%	25.39%	28.92%	35.63%	50.16%	100%
<b>T o t a l Prob.</b>	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Notes: <sup>a</sup>Each entry is the probability that a case of cancer caused by exposure at the age listed at the top of the entry's column will occur at the age listed at the left end of the entry's row.

<sup>b</sup>Based on values in Table 6-5

<sup>c</sup>Refers to cancer of the urinary bladder, colon cancer, and cancer of the rectum.

**TABLE 6-7**  
**Fatality Rate per 100,000 Individuals for Urinary Bladder Cancer, and Colon Cancer and Rectum Cancer: By Age<sup>a</sup>**

Age (Years)	Type of Cancer		Total
	Urinary Bladder <sup>b</sup>	Colon and Rectum <sup>c</sup>	
0 to 4	0	0	0
5 to 9	0	0	0
10 to 14	0	0	0
15 to 19	0	0.1	0.1
20 to 24	0	0.2	0.2
25 to 29	0	0.5	0.5
30 to 34	0.1	0.9	1.0
35 to 39	0.1	1.9	2.0
40 to 44	0.4	4.1	4.5
45 to 49	0.8	8.2	9.0
50 to 54	1.8	16.5	18.3
55 to 59	3.7	29.9	33.6
60 to 64	7.1	48.4	55.5
65 to 69	12.5	72.8	85.3
70 to 74	20.0	104.4	124.4
75 to 79	30.7	144.2	174.9
80 to 85	46.5	201.9	248.4
85+	68.6	291.4	360.0

Notes: <sup>a</sup>See note (a) for Table 6-5.

<sup>b</sup>Based on the age-specific rates listed in column 1 of Table XXXVI-3 in Ries et al. (1998).

<sup>c</sup>Based on the age-specific rates listed in column 1 of Table VI-6 in Ries et al. (1998).

**TABLE 6-8<sup>a,b,c</sup>**  
**Probability of Cancer Fatality at Age at Left End of Row if the Fatality Results from Exposure at Age at Top of Column**

	0 to 4	5 to 9	10 to 14	15 to 19	20 to 24	25 to 29	30 to 34	35 to 39	40 to 44	45 to 49	50 to 54	55 to 59	60 to 64	65 to 69	70 to 74	75 to 79	80 to 84	85+
<b>0 to 4</b>	0.00%																	
<b>5 to 9</b>	0.00%	0.00%																
<b>10 to 14</b>	0.00%	0.00%	0.00%															
<b>15 to 19</b>	0.01%	0.01%	0.01%	0.01%														
<b>20 to 24</b>	0.02%	0.02%	0.02%	0.02%	0.02%													
<b>25 to 29</b>	0.04%	0.04%	0.04%	0.04%	0.04%	0.04%												
<b>30 to 34</b>	0.09%	0.09%	0.09%	0.09%	0.09%	0.09%	0.09%											
<b>35 to 39</b>	0.18%	0.18%	0.18%	0.18%	0.18%	0.18%	0.18%	0.18%										
<b>40 to 44</b>	0.40%	0.40%	0.40%	0.40%	0.40%	0.40%	0.40%	0.40%	0.40%									
<b>45 to 49</b>	0.81%	0.81%	0.81%	0.81%	0.81%	0.81%	0.81%	0.81%	0.81%	0.81%								
<b>50 to 54</b>	1.64%	1.64%	1.64%	1.64%	1.64%	1.64%	1.64%	1.64%	1.64%	1.65%	1.66%							
<b>55 to 59</b>	3.01%	3.01%	3.01%	3.01%	3.01%	3.01%	3.01%	3.01%	3.02%	3.03%	3.05%	3.11%						
<b>60 to 64</b>	4.97%	4.97%	4.97%	4.97%	4.97%	4.97%	4.97%	4.97%	4.98%	5.00%	5.04%	5.13%	5.29%					
<b>65 to 69</b>	7.63%	7.63%	7.63%	7.63%	7.63%	7.63%	7.64%	7.64%	7.66%	7.69%	7.75%	7.88%	8.14%	8.59%				
<b>70 to 74</b>	11.13%	11.13%	11.13%	11.13%	11.13%	11.13%	11.14%	11.15%	11.17%	11.21%	11.30%	11.50%	11.86%	12.53%	13.70%			
<b>75 to 79</b>	15.65%	15.65%	15.65%	15.65%	15.65%	15.65%	15.66%	15.67%	15.70%	15.77%	15.89%	16.16%	16.68%	17.61%	19.27%	22.33%		
<b>80 to 84</b>	22.22%	22.22%	22.22%	22.22%	22.23%	22.23%	22.24%	22.26%	22.30%	22.39%	22.57%	22.96%	23.69%	25.02%	27.37%	31.71%	40.83%	
<b>85+</b>	32.21%	32.21%	32.21%	32.21%	32.21%	32.22%	32.23%	32.26%	32.32%	32.45%	32.72%	33.27%	34.33%	36.25%	39.66%	45.96%	59.17%	100%
<b>T o t a l Prob.</b>	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Notes: <sup>a</sup>Each entry is the probability that a cancer fatality caused by exposure at the age listed at the top of the entry's column will occur at the age listed at the left end of the entry's row.

<sup>b</sup>Based on values in Table 6-7

<sup>c</sup>Refers to cancer of the urinary bladder, colon cancer, and cancer of the rectum.

**6.2.2.5.  $\text{PrAlive}_{k,l}$**  — Section 5.8.2.1. of this document details the conditional probability of surviving  $l$  years once an individual reaches the age range corresponding to age cohort  $k$ .

Table 5-22 details these probabilities for the general population, while Table 5-23 details these values for the AIDS subpopulation. For example, for the general population, the probability that an individual whose age ranges from 50 to 54 survives at least another 10 years, *i.e.*, at least until age 60 to 64, is 0.930. This value is the entry in Table 5-22 for the column with the heading “50 to 54” and the left row entry of “60 to 64”.

**6.2.2.6.  $\text{QVal}_{i,\text{age}}$**  — Tables 5-25 (general population) and 5-26 (AIDS subpopulation) details the age-specific QALY values for each type of health event considered in this case study.

### **6.3. COMPUTATION OF TECHNOLOGY COSTS**

The technology cost is the net present value of the sum of the capital cost (CapCost) and the annual operating costs (OpCost) for a treatment technology. If the technology were

operational indefinitely, the net present value of the operational costs would be  $\frac{\text{OpCost}}{d}$ , where  $d$

is the annual discount rate. That portion of the operational cost attributable to years 21 onwards

amounts to  $\frac{\text{OpCost}}{d \times (1 + d)^{20}}$ . Hence, the cost attributable to years 1 through 20 is

$\left[1 - \frac{1}{(1+d)^{20}}\right] \times \frac{Op\ cost}{d}$ , and, the net present value of the capital and operational costs for a

technology over a 20-year installation period is:

$$TechCost = CapCost + \left[1 - \frac{1}{(1+d)^{20}}\right] \times \frac{OpCost}{d} \quad (6-8)$$

Table 6-9 summarizes the net present value of per capita technology costs.

#### **6.4. COMPUTATION OF THE COST EFFECTIVENESS RATIO FOR THE SUPPLEMENTAL DISINFECTION TECHNOLOGY**

The cost effectiveness ratio for the supplemental drinking water disinfection technology

(CE) is defined to be:

$$CE = \frac{TechCost_{BL+Sup} - TechCost_{BL}}{QALY_{BL} - QALY_{BL+Sup}}, \quad (6-$$

9)

where

TechCost = The technology cost of a disinfection technology – Baseline and supplemental technology (BL+Sup), or Baseline only (BL); and

QALY = The QALY costs associated with drinking water treated with either the baseline and supplemental technology (BL+Sup), or the Baseline technology only (BL).

**TABLE 6-9**  
**Per Capita Technology Costs**

Technology	Costs <sup>a</sup>		Per Capita <sup>a</sup> NPV – Discount Rate of:	
	Capital	Annual Operational	3%	5%
Ozone	\$10.43	0.87	\$23.37	\$21.27
Home Filters	\$750.00	\$125.00	\$2,610	\$2,308

*Notes:* Per Capita Costs are calculated by dividing total costs by all 460,000 members of the population served in the case of ozone, and by the 429 members of the AIDS subpopulation in the case of home filters.

Note that, in general, the value of the cost effectiveness ratio is positive because the technology costs for the baseline technology alone are less than those of the baseline and supplemental technologies together (thus making the numerator of the CE ratio positive), and the QALY costs associated with baseline technology alone tend to exceed those of the baseline and supplemental technologies together (thus making the denominator positive).<sup>10</sup>

## 6.5. RESULTS

This section describes the results of the case study's evaluation of the incremental cost effectiveness of ozone pretreatment (Section 6.5.1) and home filters (6.5.2). Section 6.5.3 summarizes the results for both supplemental technologies.

**6.5.1. Ozone Pretreatment.** Table 6-10 describes the number of events per member of the general population for each of the seven health effects considered in this case study. The table has three main panels that are divided by thick shaded bars. Each of these panels corresponds to a different subgroup within the general population. The top panel details the number of events

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<sup>10</sup> A negative CE ratio has no meaning since it implies that either QALYs were gained and dollars were saved or QALYs and dollars were both lost.

**TABLE 6-10**  
**Ozone PreTreatment: Per Capita Number of Health Events**  
**General Population: Totals over the 20 Year Lifetime of the Treatment Plant**

Group	Technology	Simulation Result	Per Capita Microbial Health Effects			Per Capita DBP-Induced Health Effects			
			Mild Illness	Moderate to Severe Illness	Death	Cancer Illness	Cancer Death	Years of Infertility	Cases of Devel. Tox
<b>General Population 50th Pctl Water Intake<sup>a</sup></b>	BL	50th pctl	5.7	0.9	8.1E-5	2.2E-5	7.6E-6	3.3E-7	1.3E-7
		Average	7.2	1.2	1.1E-4	2.9E-5	1.0E-5	3.6E-7	1.3E-7
		90th pctl	14.0	2.4	2.3E-4	4.5E-5	1.6E-5	5.7E-7	1.6E-7
	BL + Sup	50th pctl	1.4	0.2	1.9E-5	2.9E-5	1.0E-5	2.5E-7	1.1E-7
		Average	2.1	0.3	3.3E-5	3.4E-5	1.2E-5	2.8E-7	1.1E-7
		90th pctl	4.7	0.8	7.2E-5	5.0E-5	1.7E-5	4.2E-7	1.4E-7
	Delta	50th pctl	3.9	0.6	5.5E-5	-5.4E-6	-1.9E-6	7.4E-8	2.1E-8
		Average	5.0	0.8	7.9E-5	-4.7E-6	-1.6E-6	8.7E-8	2.1E-8
		90th pctl	10.1	1.7	1.6E-4	3.3E-6	1.2E-6	1.7E-7	4.1E-8
<b>General Population 90th Pctl Water Intake<sup>a</sup></b>	BL	50th pctl	9.9	1.4	1.3E-4	4.3E-5	1.5E-5	6.0E-7	2.6E-7
		Average	11.6	1.8	1.8E-4	5.7E-5	2.0E-5	6.6E-7	2.6E-7
		90th pctl	21.6	3.7	3.6E-4	8.8E-5	3.1E-5	1.0E-6	3.1E-7
	BL + Sup	50th pctl	2.6	0.4	3.5E-5	5.4E-5	1.9E-5	4.6E-7	2.2E-7
		Average	3.8	0.6	6.0E-5	6.5E-5	2.3E-5	5.1E-7	2.2E-7
		90th pctl	8.6	1.3	1.3E-4	9.5E-5	3.3E-5	7.8E-7	2.6E-7
	Delta	50th pctl	6.4	0.9	8.5E-5	-1.0E-5	-3.6E-6	1.3E-7	4.0E-8
		Average	7.7	1.2	1.2E-4	-8.0E-6	-2.8E-6	1.6E-7	4.0E-8
		90th pctl	14.8	2.5	2.4E-4	6.5E-6	2.3E-6	3.1E-7	7.9E-8
<b>Avg. for Total General Population</b>	BL	50th pctl	5.9	0.9	7.9E-5	2.5E-5	8.8E-6	3.6E-7	1.4E-7
		Average	7.5	1.2	1.1E-4	3.2E-5	1.1E-5	3.9E-7	1.5E-7
		90th pctl	14.6	2.4	2.3E-4	4.9E-5	1.7E-5	6.1E-7	1.8E-7
	BL + Sup	50th pctl	1.4	0.2	1.9E-5	3.2E-5	1.1E-5	2.7E-7	1.2E-7
		Average	2.3	0.4	3.3E-5	3.7E-5	1.3E-5	3.0E-7	1.2E-7
		90th pctl	5.1	0.8	7.9E-5	5.4E-5	1.9E-5	4.5E-7	1.5E-7
	Delta	50th pctl	4.0	0.6	5.1E-5	-5.8E-6	-2.0E-6	8.2E-8	2.4E-8
		Average	5.2	0.8	7.6E-5	-4.9E-6	-1.7E-6	9.3E-8	2.4E-8
		90th pctl	10.3	1.7	1.6E-4	2.9E-6	1.0E-6	1.8E-7	4.7E-8



per individual for those members of the population whose drinking water intake equals the median value for the entire population (i.e., for both total tap water intake and for unheated tap water intake). The middle panel details the per capita number of health events for heavy consumers of tap water – i.e., those whose consumption is at the 90th percentile for the population. The bottom panel details the number of health events expected for an individual whose consumption is equal to the arithmetic average intake rate for the entire general population. The event counts in the bottom panel are also equal to the per capita number of events averaged over all members of the population. The number of events per individual with average consumption equals the average number of events per member of the population because the relationship between risk and consumption is linear<sup>11</sup>. Differences among the three main panels are attributable to variability in the general population due to differences in tap water consumption rates.

Each of the three main panels in Table 6-10 is further subdivided into three sections – one quantifying the per capita number of health events associated with the baseline technology, one quantifying the per capita number of health events associated with the baseline technology supplemented with ozone pretreatment, and a third (designated “delta”) that quantifies the difference between these two – i.e., the incremental per capita number of health events prevented by implementing the supplemental technology. For each technology, and for the delta, Table 6-10 characterizes uncertainty by listing the 50th percentile Monte Carlo result, the average among all 1,000 Monte Carlo results, and the 90th percentile result. For example, referring to the

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<sup>11</sup> Recall that DBP-induced risks are the product of the consumption rate and a slope factor. The probability of *Cryptosporidium* infection is an exponential function of consumption. However, because the infectivity parameter is so small, this probability (and the conditional probability of mild illness, moderate to severe illness, and death) can be predicted as an almost perfectly linear function of consumption. Because the average of a linear function of some value is equal to the linear function of the average of that value, it follows that the average population risk (i.e., the average of a linear function of water consumption) is equal to the risk for an individual whose consumption is equal to the average rate for the population (i.e., a linear function of the average consumption).

bottom panel of Table 6-10, there is a 50% chance that with the baseline technology in place (i.e., without the supplemental ozone treatment), the general population will experience at least 5.9 mild *Cryptosporidium* illnesses per person during the 20-year life of the treatment plant. There is a 10% probability that this number will exceed 14.6 illnesses per person over that period. The “expected” number of illnesses is 7.5 per person.

Table 6-11 is analogous to Table 6-10. In place of health events per person, it lists the cost of those events in terms of lost QALYs during the 20-year analytical time frame of the analysis. These costs reflect the assumption of a 3% discount rate. The results in the “delta” portion of each panel of Table 6-11 can be used to compute the cost-effectiveness of the supplemental technology. For example, for an individual whose consumption rate equals the average for the entire general population, there is a 50% chance that the per-capita health benefit is at least  $7.9 \times 10^{-3}$  QALYs, whereas the net present value of the incremental per capita technology cost is \$23.37. Hence, the median cost-effectiveness ratio for this average consumer is computed as  $\$23.37 \div (7.9 \times 10^{-3})$ , or \$2,928 per QALY. Similarly, there is a 10% chance that the net present value of the health benefits for the average consumer exceeds  $2.6 \times 10^{-2}$  QALYs. As a result, there is a 10% chance that the cost-effectiveness ratio is more favorable (i.e., smaller than) \$912 per QALY. Figure 6-3 plots the cumulative probability distribution function for the cost-effectiveness ratio. Note that Table 6-11 does not report the ratio of the incremental per capita technology cost to the average per capita QALY gain (values that would appear in table entries marked “NA<sup>b</sup>”) because this ratio does not equal the average of the 1,000 Monte Carlo

**TABLE 6-11**  
**Ozone PreTreatment: Cost Effectiveness – Discount Rate of 3%**  
**General Population: Totals over the 20 Year Lifetime of the Treatment Plant**

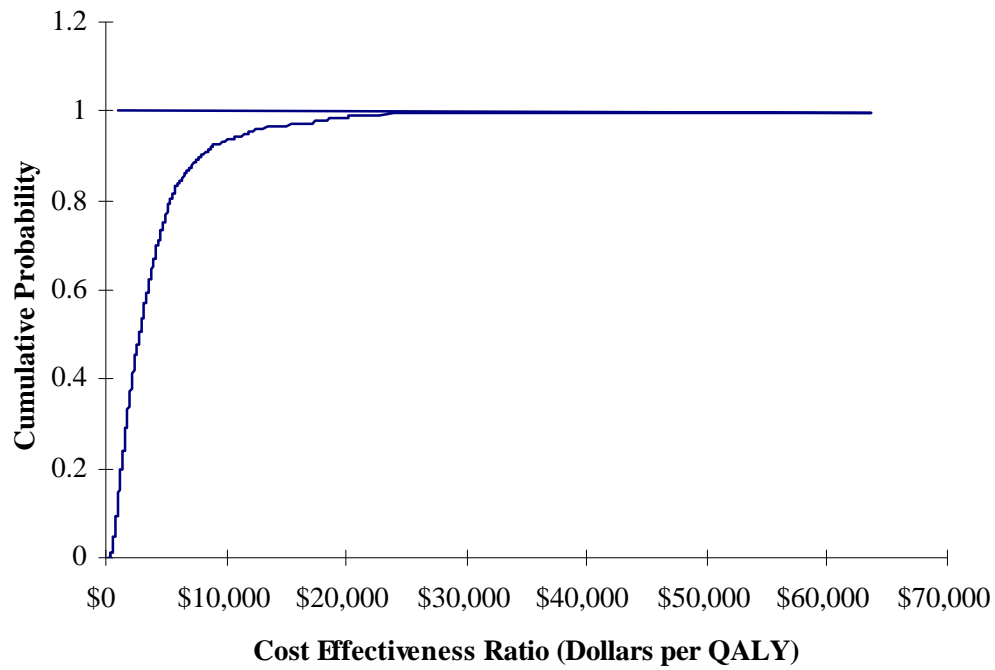
Group	Technology	Simulation Result	Per Capita Microbial Health Effects			Per Capita DBP-Induced Health Effects				Tech Costs (\$/person)	QALYs per person	CE Ratio (\$/QALY)
			Mild Illness	Mod. to Severe Illness	Death	Cancer Illness	Cancer Death	Repro. Tox	Devel. Tox			
General Population 50th Pctl Water Intake	BL	50th pctl	3.2E-3	7.0E-3	1.4E-3	3.0E-6	1.2E-5	3.0E-8	1.4E-6		1.2E-2	
		Average	4.5E-3	1.0E-2	2.0E-3	4.0E-6	1.6E-5	3.5E-8	1.5E-6	NA <sup>a</sup>	1.7E-2	NA <sup>a</sup>
		90th pctl	9.5E-3	2.1E-2	4.0E-3	7.2E-6	3.0E-5	6.0E-8	2.5E-6		3.5E-2	
	BL + Sup	50th pctl	7.7E-4	1.7E-3	3.3E-4	3.7E-6	1.5E-5	2.3E-8	1.2E-6		2.8E-3	
		Average	1.3E-3	2.9E-3	5.9E-4	4.6E-6	1.9E-5	2.6E-8	1.3E-6	NA <sup>a</sup>	4.9E-3	NA <sup>a</sup>
		90th pctl	3.0E-3	6.5E-3	1.3E-3	7.8E-6	3.3E-5	4.5E-8	2.1E-6		1.1E-2	
	Delta	50th pctl	2.2E-3	4.8E-3	8.8E-4	-6.7E-7	-2.7E-6	6.6E-9	2.1E-7	\$23.37	7.9E-3	\$2,964
		Average	3.2E-3	7.1E-3	1.4E-3	-6.4E-7	-2.7E-6	8.3E-9	2.5E-7	\$23.37	1.2E-2	NA <sup>b</sup>
		90th pctl	7.0E-3	1.5E-2	2.9E-3	4.3E-7	1.7E-6	1.7E-8	5.5E-7	\$23.37	2.5E-2	\$949
General Population 90th Pctl Water Intake	BL	50th pctl	5.7E-3	1.2E-2	2.2E-3	5.5E-6	2.3E-5	5.3E-8	2.8E-6		1.9E-2	
		Average	7.1E-3	1.6E-2	3.2E-3	7.5E-6	3.1E-5	6.3E-8	3.0E-6	NA <sup>a</sup>	2.6E-2	NA <sup>a</sup>
		90th pctl	1.4E-2	3.3E-2	6.9E-3	1.3E-5	5.4E-5	1.1E-7	4.8E-6		5.4E-2	
	BL + Sup	50th pctl	1.6E-3	3.0E-3	5.8E-4	7.1E-6	2.8E-5	4.0E-8	2.3E-6		5.2E-3	
		Average	2.4E-3	5.5E-3	1.1E-3	8.6E-6	3.6E-5	4.8E-8	2.6E-6	NA <sup>a</sup>	8.9E-3	NA <sup>a</sup>
		90th pctl	5.6E-3	1.2E-2	2.7E-3	1.4E-5	5.9E-5	8.7E-8	4.1E-6		2.1E-2	
	Delta	50th pctl	3.7E-3	7.4E-3	1.5E-3	-1.2E-6	-5.1E-6	1.1E-8	4.0E-7	\$23.37	1.3E-2	\$1,825
		Average	4.8E-3	1.0E-2	2.1E-3	-1.1E-6	-4.7E-6	1.5E-8	4.7E-7	\$23.37	1.7E-2	NA <sup>b</sup>
		90th pctl	9.2E-3	2.3E-2	4.7E-3	7.2E-7	2.9E-6	3.1E-8	1.0E-6	\$23.37	3.7E-2	\$624
Avg. for Total General Population	BL	50th pctl	3.4E-3	6.9E-3	1.3E-3	3.3E-6	1.4E-5	3.0E-8	1.5E-6		1.2E-2	
		Average	4.7E-3	1.0E-2	1.9E-3	4.5E-6	1.9E-5	3.6E-8	1.7E-6	NA <sup>a</sup>	1.7E-2	NA <sup>a</sup>
		90th pctl	9.4E-3	2.2E-2	4.1E-3	7.6E-6	3.2E-5	6.4E-8	2.8E-6		3.6E-2	
	BL + Sup	50th pctl	8.6E-4	1.7E-3	3.1E-4	4.2E-6	1.7E-5	2.4E-8	1.3E-6		2.9E-3	
		Average	1.4E-3	3.1E-3	5.6E-4	5.1E-6	2.1E-5	2.7E-8	1.4E-6	NA <sup>a</sup>	5.1E-3	NA <sup>a</sup>
		90th pctl	3.2E-3	7.7E-3	1.4E-3	8.4E-6	3.5E-5	4.8E-8	2.3E-6		1.2E-2	

Group	Technology	Simulation Result	Mild Illness	Mod. to Severe Illness	Death	Cancer Illness	Cancer Death	Repro. Tox	Devel. Tox	Tech Costs (\$/person)	QALYs per person	CE Ratio (\$/QALY)
	Delta	50th pctl	2.3E-3	4.7E-3	8.9E-4	-7.0E-7	-2.9E-6	6.8E-9	2.3E-7	\$23.37	7.9E-3	\$2,928
		Average	3.3E-3	7.1E-3	1.3E-3	-6.4E-7	-2.7E-6	8.6E-9	2.8E-7	\$23.37	1.2E-2	NA <sup>b</sup>
		90th pctl	6.8E-3	1.6E-2	3.1E-3	3.7E-7	1.6E-6	1.7E-8	6.2E-7	\$23.37	2.6E-2	\$912

Notes: NA<sup>a</sup> These values are not provided for the baseline technology and for the supplemental technology because computation of the cost-effectiveness ratio only makes sense when considering the incremental difference between the two, as described in the "Delta" row of this table.

NA<sup>b</sup> Division of the average per capita technology cost by the average incremental QALY gain is not reported since it does not equal the average cost-effectiveness ratio.

**Figure 6-3**  
**Cumulative Distribution for the Cost-Effectiveness Ratio for Ozone**  
**Pretreatment:**  
**General Population**



generated cost effectiveness ratio values. The expected value of the cost effectiveness ratio (the arithmetic average of its values over the 1,000 Monte Carlo generated values is \$4134 per QALY. This result does not equal \$23.37 divided by the average per capita QALY gain because the inverse of the expected value of a quantity (i.e., \$23.37 divided by the average of the incremental QALY gain of  $1.2 \times 10^{-2}$ ) does not equal the expected value of the inverse of that quantity (i.e., the average cost effectiveness ratio).

Table 6-12 lists health events and QALY costs (assuming a 3% discount rate) summed over all members of the general population. Because these numbers represent totals over the entire general population, it does not make sense to break these results out by subgroups within the general population, as was done in Tables 6-10 and 6-11. The far right column of the bottom panel in Table 6-12 lists QALYs summed over all health endpoints. This quantity has meaning because the QALY is a common metric. The far right column therefore quantifies the health costs associated with each treatment technology, and also characterizes the uncertainty in this value. Table 6-12 does not sum health event counts across endpoints (i.e., the far right column in the top panel in Table 6-12 is blank) because the endpoints are not directly comparable.

Table 6-13 reports event counts and the corresponding QALY values quantifying the benefit of the ozone post-treatment technology for members of the AIDS subpopulation. A comparison of Tables 6-12 and 6-13 reveals that for both the general population and the AIDS subpopulation, DBP-induced health effects are far fewer and have a far smaller QALY cost than do health effects stemming from microbial infection. The general population, by virtue of its size accounts for the bulk of the bulk of the events and QALY costs associated with microbial morbidity. However, because the conditional risk of death given moderate to severe infection for

**TABLE 6-12**  
**Ozone PreTreatment: General Population Event Counts and QALY Value of Health Events – Discount Rate of 3%**  
**Size: 460,000 Individuals – Results over the 20 Year Plant Life**

Group	Technology	Simulation Result	Population Microbial Health Effects			Population DBP-Induced Health Effects				
			Mild Illness	Mod. to Severe Illness	Death	Cancer Illness	Cancer Death	Repro. Tox	Devel. Tox	
Number of Events	BL	50th pctl	2,700,338	411,426	36.2	11.6	4.04	0.16	0.067	
		Average	3,431,943	542,403	50.1	14.7	5.15	0.18	0.067	
		90th pctl	6,730,582	1,118,554	105.4	22.4	7.83	0.28	0.081	
	BL + Sup	50th pctl	663,622	95,570	8.5	14.6	5.10	0.12	0.056	
		Average	1,037,890	164,005	15.2	17.0	5.94	0.14	0.056	
		90th pctl	2,348,330	374,918	36.4	24.6	8.62	0.21	0.067	
	Delta	50th pctl	1,826,332	272,141	23.5	-2.7	-0.93	0.04	0.011	
		Average	2,394,053	378,398	34.9	-2.3	-0.79	0.04	0.011	
		90th pctl	4,749,195	804,142	75.3	1.3	0.46	0.08	0.022	
QALYs	BL	50th pctl	1,567	3,189	598	1.51	6.31	0.014	0.71	Total QALYs
		Average	2,155	4,683	872	2.05	8.56	0.017	0.78	5,363
		90th pctl	4,330	10,117	1,898	3.48	14.80	0.030	1.29	7,721
	BL + Sup	50th pctl	393	776	145	1.95	8.03	0.011	0.59	16,365
		Average	650	1,428	260	2.35	9.80	0.013	0.65	1,325
		90th pctl	1,466	3,531	623	3.85	16.28	0.022	1.06	2,350
	Delta	50th pctl	1,074	2,175	407	-0.32	-1.34	0.003	0.11	5,641
		Average	1,505	3,255	613	-0.29	-1.25	0.004	0.13	3,654
		90th pctl	3,132	7,375	1,403	0.17	0.71	0.008	0.29	5,372

**TABLE 6-13**  
**Ozone PreTreatment: AIDS Subpopulation Event Counts and QALY Value of Health Events – Discount Rate of 3%**  
**Size: 429 Individuals – Results over the 20 Year Plant Life**

Group	Technology	Simulation Result	Population Microbial Health Effects			Population DBP-Induced Health Effects				
			Mild Illness	Mod. to Severe Illness	Death	Cancer Illness	Cancer Death	Repro. Tox	Devel. Tox	
Number of Events	BL	50th pctl	11,359	10,510	2,392	9.2E-3	3.2E-3	0	0	
		Average	12,447	11,431	2,607	1.2E-2	4.3E-3	0	0	
		90th pctl	21,085	19,644	4,410	2.1E-2	7.3E-3	0	0	
	BL + Sup	50th pctl	2,909	2,626	608	1.2E-2	4.1E-3	0	0	
		Average	3,988	3,667	856	1.4E-2	4.9E-3	0	0	
		90th pctl	8,761	8,116	1,937	2.2E-2	7.7E-3	0	0	
	Delta	50th pctl	7,624	7,009	1,605	-2.3E-3	-8.0E-4	0	0	
		Average	8,458	7,764	1,751	-1.7E-3	-6.0E-4	0	0	
		90th pctl	15,176	14,062	3,108	1.7E-3	5.8E-4	0	0	
QALYs	BL	50th pctl	3.0	39.6	9,342	4.3E-5	5.6E-3	0	0	Total QALYs
		Average	3.5	46.6	11,314	5.8E-5	7.6E-3	0	0	9,385
		90th pctl	6.7	88.8	21,281	1.0E-4	1.3E-2	0	0	11,364
	BL + Sup	50th pctl	0.7	9.7	2,439	5.5E-5	7.1E-3	0	0	21,376
		Average	1.1	15.1	3,664	6.6E-5	8.7E-3	0	0	2,450
		90th pctl	2.6	34.6	8,267	1.1E-4	1.5E-2	0	0	3,680
	Delta	50th pctl	1.9	26.3	6,018	-9.1E-6	-1.2E-3	0	0	8,304
		Average	2.4	31.5	7,650	-8.2E-6	-1.1E-3	0	0	6,046
		90th pctl	4.7	61.4	14,868	7.9E-6	9.3E-4	0	0	7,684
										14,934



the AIDS population exceeds the corresponding risk for the general population by 3 orders of magnitude, and because the risk of illness for the AIDS subpopulation exceeds the corresponding risks for the general population, the AIDS subpopulation experiences far more microbial-related fatality. And, although the QALY cost of death is less for the AIDS subpopulation than it is for the general population because members of the former have a far shorter life expectancy, the AIDS subpopulation QALY costs for this endpoint exceed the corresponding QALY costs for the general population. As a result, these costs for the AIDS subpopulation are comparable to those for the general population despite the fact that the AIDS subpopulation accounts for such a small fraction of the total population.

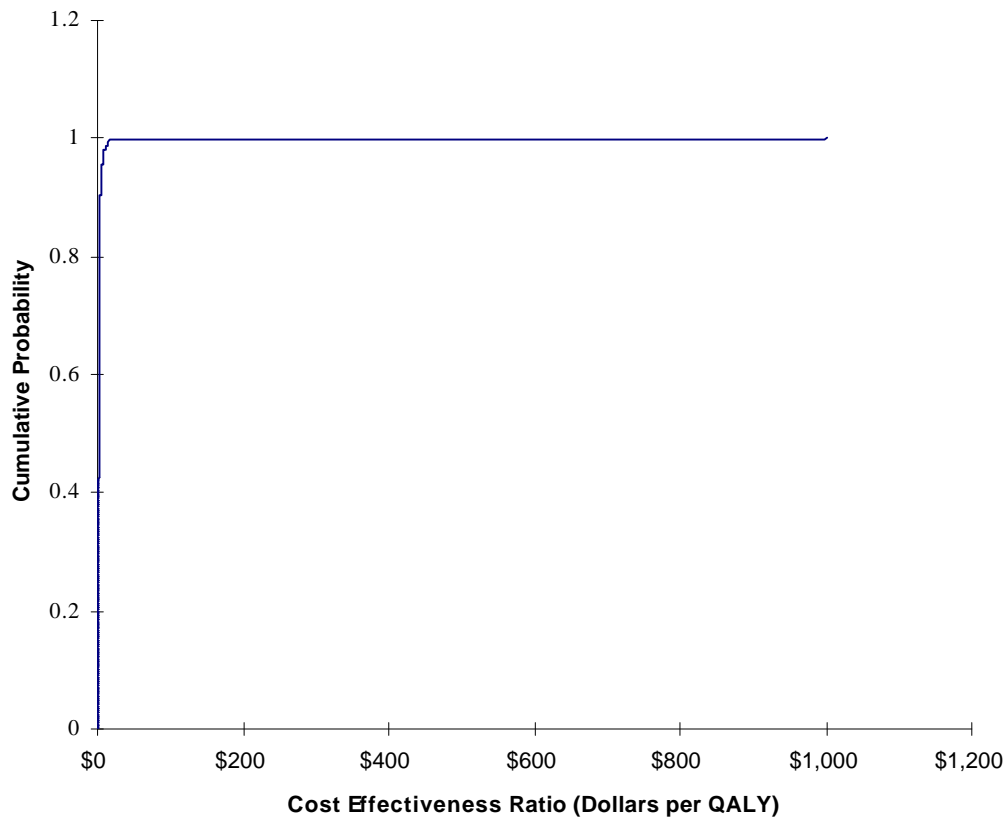
Based on these results, it is not surprising that the ozone pretreatment cost-effectiveness ratio for members of the AIDS subpopulation (\$23.37 divided by the per capita QALY benefits) is very favorable. As detailed in Table 6-13, ozone pretreatment confers an expected net benefit of 7,684 QALYs for the entire AIDS subpopulation, or approximately 18 QALYs per member of the population<sup>12</sup>. The average cost-effectiveness ratio for the AIDS subpopulation is an amazingly low \$2.27 per QALY. The difference between this value and the average for the general population of \$4,134 per QALY plainly demonstrates that the AIDS subpopulation is a key beneficiary of technology that reduces *Cryptosporidium* concentrations in tap water. Figure 6-4 plots the cumulative distribution for the AIDS subpopulation cost-effectiveness ratio.

Table 6-14 sums the results in Tables 6-12 and 6-13 to quantify the benefits of this technology for the entire population. Note that results for the 50th percentile and 90th percentile

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<sup>12</sup> Referring to this gain of 18 QALYs as a per capita value is misleading since very few members of the AIDS subpopulation will survive the entire 20-year analytical time frame for this analysis. In reality, many of these individuals will die, only to be replaced by others who develop AIDS. The 18 QALY “per person” gain is therefore shared among all individuals who share a “slot” in the AIDS subpopulation over the 20-year analytical time frame for this analysis..

**Figure 6-4**  
**Cumulative Distribution for the Cost-Effectiveness Ratio**  
**for Ozone Pretreatment:**  
**AIDS subpopulation**



**TABLE 6-14<sup>a</sup>**  
**Ozone PreTreatment: Total Population Event Counts and QALY Value of Health Events – Discount Rate of 3%**  
**Results over the 20 Year Plant Life**

Group	Technology	Simulation Result	Population Microbial Health Effects			Population DBP-Induced Health Effects				
			Mild Illness	Mod. to Severe Illness	Death	Cancer Illness	Cancer Death	Repro. Tox	Devel. Tox	
Number of Events	BL	50th pctl	2,711,697	421,936	2,428	11.6	4.0	0.16	0.067	
		Average	3,444,390	553,834	2,657	14.7	5.2	0.18	0.067	
		90th pctl	6,751,667	1,138,198	4,515	22.4	7.8	0.28	0.081	
	BL + Sup	50th pctl	666,531	98,196	617	14.6	5.1	0.12	0.056	
		Average	1,041,878	167,672	871	17.0	5.9	0.14	0.056	
		90th pctl	2,357,091	383,034	1,973	24.6	8.6	0.21	0.067	
	Delta	50th pctl	1,833,956	279,150	1,629	-2.7	-0.9	0.04	0.011	
		Average	2,402,511	386,162	1,786	-2.3	-0.8	0.04	0.011	
		90th pctl	4,764,371	818,204	3,183	1.3	0.5	0.08	0.022	
										Total QALYs
QALYs	BL	50th pctl	1,570	3,229	9,940	1.51	6.31	0.014	0.71	14,747
		Average	2,158	4,729	12,187	2.05	8.56	0.017	0.78	19,086
		90th pctl	4,337	10,206	23,179	3.48	14.81	0.030	1.29	37,741
	BL + Sup	50th pctl	394	786	2,584	1.95	8.04	0.011	0.59	3,775
		Average	651	1,443	3,924	2.35	9.81	0.013	0.65	6,030
		90th pctl	1,469	3,566	8,889	3.85	16.29	0.022	1.06	13,945
	Delta	50th pctl	1,075	2,201	6,425	-0.32	-1.34	0.003	0.11	9,700
		Average	1,508	3,287	8,263	-0.29	-1.25	0.004	0.13	13,056
		90th pctl	3,137	7,437	16,271	0.17	0.72	0.008	0.29	26,846

Notes: Results are the sum of the corresponding values in Tables 6-5-3a and 6-5-3b. Note that the 50th percentile and 90th percentile results are approximations. See accompanying text.

are only approximate since the summation of the corresponding values in Tables 6-12 and 6-13 is based on the assumption that event counts and QALY values for the general population and AIDS subpopulation are perfectly correlated with respect to the uncertain quantities in this analysis.

This assumption is reasonable since the calculations for these two populations depend on many of the same quantities (e.g., the source water *Cryptosporidium* concentration). Moreover, it is reasonable to suspect that other sets of assumptions are positively correlated (e.g., the *Cryptosporidium* infectivity parameters for the general population and the AIDS subpopulation).

Note that the accuracy of the average QALY cost estimates and the average event count estimates do not depend on the assumption of a perfect correlation between the general population results and the AIDS subpopulation results.

Ideally, the total population cost-effectiveness ratio would be calculated by summing QALY gains for the general population and AIDS subpopulation for each set of assumptions randomly generated as part of the Monte Carlo analysis, dividing this gain into the total population technology cost of approximately \$10.8 million, and then averaging these 1,000 quotients. However, because the case study calculated benefits for the general population and AIDS subpopulation separately, this is not directly possible. Instead, the 1,000 Monte Carlo generated QALY gains for the general population and the 1,000 Monte Carlo generated QALY gains for the AIDS subpopulation were both sorted and corresponding QALY gains were then summed (i.e., the smallest generated general population QALY gain was added to the smallest generated AIDS subpopulation QALY gain, the two second smallest gains were summed, and so forth). Each of the resulting sums were divided into the total incremental technology cost of approximately \$10.8 million and the average was calculated for the resulting quotients. The

average cost-effectiveness ratio thus calculated is \$1,532 dollars per QALY. This approximation is reasonable since, for reasons discussed earlier, it is likely that net benefits for the general population and AIDS subpopulation are highly correlated. Direct computation of this value could be accomplished through further enhancement of the Monte Carlo software used for this case study.

Finally, Table 6-15 quantifies the incremental fraction of the variance in the cost-effectiveness ratio for the general population that is attributable to each of the uncertain parameters. Parameters influencing the predicted number of *Cryptosporidium* illnesses have the strongest influence on the cost-effectiveness ratio. The QALY cost assignments for these health endpoints are also moderately influential. These results are not surprising since, as detailed in Table 6-14, *Cryptosporidium* illness is responsible for much of the cost associated with ingestion of tap water. More importantly, most of the QALY gain accrued by the new technology reflects a reduction in the number of *Cryptosporidium* illnesses. Table 6-16 quantifies the incremental fraction of the variance in the cost-effectiveness ratio for the AIDS subpopulation. The results are similar to those in Table 6-15, although parameters related to the quantification of costs associated with *Cryptosporidium* fatalities (rather than morbidity, *per se*) are somewhat more important for the AIDS subpopulation than they are for the general population.

**6.5.2. Home Filters.** Because the case study does not investigate the impact of water consumption variability among members of the AIDS subpopulation, the content corresponding to that in Tables 6-10 and 6-11 is not reported for home filters. Instead, only total event counts and total QALY values appear. These findings, which are in Table 6-17, correspond to the

**TABLE 6-15**  
**Ozone PreTreatment: Sensitivity Analysis – CE Ratio for the General Population**

Parameter	Section Discussing Parameter	Incremental Variance Explained
<i>Cryptosporidium</i> Concentration		
Source water concentration		7.2%
Supplemental technology removal efficiency		8.6%
Fraction of ingested tap water that is unheated		0.6%
<i>Cryptosporidium</i> Toxicity		
Infectivity Parameter		5.8%
Conditional prob of mild illness given infection		5.5%
Conditional prob of mod to severe illness given mild illness		3.1%
Conditional prob of death given mod to severe illness		< 0.5%
DBP Toxicity		
Baseline technology – cancer slope factor		< 0.5%
Baseline technology – developmental tox slope factor		< 0.5%
Baseline technology – reproductive tox slope factor		< 0.5%
Baseline technology – cancer slope factor		< 0.5%
Baseline technology – developmental tox slope factor		< 0.5%
Baseline technology – reproductive tox slope factor		< 0.5%
Economic Parameters		
Value of mild <i>Cryptosporidium</i> illness		1.3%
Value of moderate to severe <i>Cryptosporidium</i> illness		3.3%
Value of death due to <i>Cryptosporidium</i> infection		< 0.5%
Value of cancer illness		< 0.5%
Value of cancer mortality		< 0.5%
Value of developmental effects		< 0.5%
Value of 1 year of infertility (reproductive tox)		< 0.5%

*Notes: The incremental variance explained is computed by dividing each parameter's Type III sums of squares by the total sums of squares. This resulting value is the variance explained by the parameter when it is entered into the regression after all other parameters being tested are entered.*

**TABLE 6-16**  
**Ozone PreTreatment: Sensitivity Analysis – CE Ratio for the AIDS Subpopulation**

Parameter	Section Discussing Parameter	Incremental Variance Explained
<i>Cryptosporidium</i> Concentration		
Source water concentration		8.1%
Supplemental technology removal efficiency		15.1%
Fraction of ingested tap water that is unheated		0.7%
<i>Cryptosporidium</i> Toxicity		
Infectivity Parameter		8.8%
Conditional prob of mild illness given infection		< 0.5%
Conditional prob of mod to severe illness given mild illness		< 0.5%
Conditional prob of death given mod to severe illness		1.7%
DBP Toxicity		
Baseline technology – cancer slope factor		< 0.5%
Baseline technology – developmental tox slope factor		< 0.5%
Baseline technology – reproductive tox slope factor		< 0.5%
Baseline technology – cancer slope factor		< 0.5%
Baseline technology – developmental tox slope factor		< 0.5%
Baseline technology – reproductive tox slope factor		< 0.5%
Economic Parameters		
Value of mild <i>Cryptosporidium</i> illness		< 0.5%
Value of moderate to severe <i>Cryptosporidium</i> illness		< 0.5%
Value of death due to <i>Cryptosporidium</i> infection		9.7%
Value of cancer illness		< 0.5%
Value of cancer mortality		< 0.5%
Value of developmental effects		< 0.5%
Value of 1 year of infertility (reproductive tox)		< 0.5%

*Notes: The incremental variance explained is computed by dividing each parameter's Type III sums of squares by the total sums of squares. This resulting value is the variance explained by the parameter when it is entered into the regression after all other parameters being tested are entered.*

**TABLE 6-17**  
**AIDS Population Event Counts and QALY Value of Health Events – Discount Rate of 3%**  
**Size: 429 Individuals – Results for 20 Years of Home Filter Use**

Group	Technology	Simulation Result	Population Microbial Health Effects			Population DBP-Induced Health Effects					
			Mild Illness	Mod. to Severe Illness	Death	Cancer Illness	Cancer Death	Repro. Tox	Devel. Tox		
Number of Events	BL	50th pctl	11,561	10,543	2,369	9.2E-3	3.2E-3	0	0		
		Average	12,467	11,468	2,608	1.2E-2	4.3E-3	0	0		
		90th pctl	21,234	19,674	4,433	1.9E-2	6.6E-3	0	0		
	BL + Sup	50th pctl	0	0	0	1.2E-2	4.1E-3	0	0		
		Average	0	0	0	1.4E-2	4.9E-3	0	0		
		90th pctl	0	0	0	2.1E-2	7.2E-3	0	0		
	Delta	50th pctl	11,561	10,543	2,369	-2.3E-3	-7.9E-4	0	0		
		Average	12,467	11,468	2,608	-1.6E-3	-5.5E-4	0	0		
		90th pctl	21,234	19,674	4,433	1.3E-3	4.6E-4	0	0		
QALYs	BL	50th pctl	3.0	37.3	9,587	4.1E-5	5.6E-3	0	0	Total QALYs	
		Average	3.6	45.4	11,587	5.8E-5	7.8E-3	0	0	9,627	
		90th pctl	6.7	89.4	22,470	9.5E-5	1.3E-2	0	0	11,636	
	BL + Sup	50th pctl	0.0	0.0	0	5.3E-5	7.3E-3	0	0	22,566	
		Average	0.0	0.0	0	6.5E-5	8.8E-3	0	0	0	
		90th pctl	0.0	0.0	0	1.1E-4	1.5E-2	0	0	0	
	Delta	50th pctl	3.0	37.3	9,587	-8.8E-6	-1.2E-3	0	0	0	
		Average	3.6	45.4	11,587	-7.4E-6	-1.1E-3	0	0	9,627	
		90th pctl	6.7	89.4	22,470	5.7E-6	8.1E-4	0	0	11,636	
											22,566



content of Table 6-13. The baseline technology entries in Table 6-17 are very similar to those in Table 6-13 because both represent health event counts and health costs for the AIDS subpopulation in the absence of any supplemental disinfection technology. (The similarity between these two sets of entries also indicates that 1,000 iterations yielded sufficiently precise results, at least for the AIDS subpopulation, even towards the tail end of the distribution; e.g., at the 90th percentile, the two sets of entries differ by approximately 1%.)

Home filters were assumed not to affect DBP concentrations. As a result, the “delta” rows in Table 6-17 are zero for the DBP-induced endpoints. On the other hand, home filters completely eliminate microbial morbidity and mortality, whereas ozone filtration reduces these risks by on the order of 50 to 75% (compare the delta entries in Table 6-13 to their corresponding baseline entries). This gain comes at a substantial per capita technology cost of more than \$2,600. Nonetheless, the cost-effectiveness ratio for this technology is highly favorable, with an average of approximately \$150 per QALY. The AIDS subpopulation cost effectiveness ratio of only \$2 per QALY for the ozone technology reflects the fact that, unlike home filters, the costs for the ozone technology is divided over the entire population of consumers. It should also be noted that the home filter technology would have a favorable cost-effectiveness ratio even if the ozone supplemental technology were in place and had eliminated, for example, 75% of the risks stemming from microbial infection. In this case, the average cost-effectiveness ratio for the home filter technology would be approximately 4 times higher than the value computed here, or approximately \$600 per QALY.

Table 6-18 details the sensitivity analysis for this supplemental technology. The results are, not surprisingly, qualitatively similar to the corresponding AIDS subpopulation sensitivity analysis for the ozone supplemental technology (see Table 6-16).

**6.5.3. Case Study Results Summary.** Tables 6-19 and 6-20 summarize the cost-effectiveness information for the ozone and home filter strategies assuming a 3% discount rate (Table 6-19) or a 5% discount rate (Table 6-20). Both tables highlight the finding that the AIDS subpopulation accounts for more than half the QALY gain achieved by ozone pretreatment. As such, the cost-effectiveness of ozone pretreatment for the entire population is more than twice as favorable as the cost-effectiveness ratio for the general population alone. The cost-effectiveness of the home filter technology is highly favorable despite its high per-person cost because it can be targeted to the members of the AIDS subpopulation.

Use of a 5% discount rate rather than a 3% discount rate has a modest effect on the results. The NPV of the technology costs are somewhat lower because a lower value is placed on the operational costs that occur over the 20-year analytical time frame of the analysis. The NPV of the QALY gains decrease to an even greater extent, apparently because some of the benefits reflect saved QALYs that are even further in the future. This phenomenon is particularly relevant to the valuation of *Cryptosporidium*-related deaths because they cost life years that would have been enjoyed during a period following exposure, and hence potentially beyond the 20 year analytical time frame of this analysis. Perhaps for this reason and because the AIDS subpopulation incurs so many more *Cryptosporidium*-related deaths, the QALY totals for the AIDS subpopulation in Tables 6-19 and 6-20 differ proportionally to a greater extent (7,684 vs

**TABLE 6-18**  
**Home Filters: Sensitivity Analysis – CE Ratio for the AIDS Subpopulation**

Parameter	Section Discussing Parameter	Incremental Variance Explained
<i>Cryptosporidium</i> Concentration		
Source water concentration		20.6%
Supplemental technology removal efficiency		< 0.5%
Fraction of ingested tap water that is unheated		1.2%
<i>Cryptosporidium</i> Toxicity		
Infectivity Parameter		16.7%
Conditional prob of mild illness given infection		< 0.5%
Conditional prob of mod to severe illness given mild illness		< 0.5%
Conditional prob of death given mod to severe illness		4.4%
DBP Toxicity		
Baseline technology – cancer slope factor		< 0.5%
Baseline technology – developmental tox slope factor		< 0.5%
Baseline technology – reproductive tox slope factor		< 0.5%
Baseline technology – cancer slope factor		< 0.5%
Baseline technology – developmental tox slope factor		< 0.5%
Baseline technology – reproductive tox slope factor		< 0.5%
Economic Parameters		
Value of mild <i>Cryptosporidium</i> illness		< 0.5%
Value of moderate to severe <i>Cryptosporidium</i> illness		< 0.5%
Value of death due to <i>Cryptosporidium</i> infection		20.5%
Value of cancer illness		< 0.5%
Value of cancer mortality		< 0.5%
Value of developmental effects		< 0.5%
Value of 1 year of infertility (reproductive tox)		< 0.5%

*Notes:* The incremental variance explained is computed by dividing each parameter's Type III sums of squares by the total sums of squares. This resulting value is the variance explained by the parameter when it is entered into the regression after all other parameters being tested are entered.

**TABLE 6-19**  
**Results Summary: 3% Discount Rate**  
**General Population of 460,000 Individuals and AIDS Subpopulation of 429 Individuals -**  
**20 Year Analytical Time Frame**

		NPV of Total Incremental Cost (Dollars)	NPV of Total Incremental QALYs	Expected Cost Effectiveness Ratio (\$ per QALY)
Ozone	General Population <sup>a</sup>	\$10,800,000	5,372	\$4,134 <sup>c</sup>
	AIDS Subpopulation	\$10,000	7,684	\$2.27
	Total Population	\$10,800,000 <sup>b</sup>	13,056	\$1,532
Home Filters	AIDS Subpopulation	\$1,130,000	11,636	\$152

Notes: <sup>a</sup>General population results represent the average (i.e., expected value) for the average tap water consumer.

<sup>b</sup>The total population cost is rounded and hence does not equal the sum of general population and AIDS subpopulation costs. This rounding is consistent with the imprecision in the estimated size of these two groups.

<sup>c</sup>The average CE ratio does not equal the incremental technology cost divided by the average QALY gain.

**TABLE 6-20**  
**Results Summary: 5% Discount Rate**  
**General Population of 460,000 Individuals and AIDS Subpopulation of 429 Individuals -**  
**20 Year Analytical Time Frame**

		NPV of Total Incremental Cost (Dollars)	NPV of Total Incremental QALYs	Expected Cost Effectiveness Ratio (\$ per QALY)
Ozone	General Population <sup>a</sup>	\$9,780,000	4,519	\$4,235 <sup>c</sup>
	AIDS Subpopulation	\$9,120	5,901	\$2.71
	Total Population	\$9,780,000 <sup>b</sup>	10,420	\$1,719
Home Filters	AIDS Subpopulation	\$997,000	8,746	\$178

Notes: <sup>a</sup>General population results represent the average (i.e., expected value) for the average tap water consumer.

<sup>b</sup>The total population cost is rounded and hence does not equal the sum of general population and AIDS subpopulation costs. This rounding is consistent with the imprecision in the estimated size of these two groups.

<sup>c</sup>See note c following Table 6-19.

5,901) than do the totals for the general population (5,372 vs 4,519). This result was not entirely expected because members of the general population have far longer life expectancies than do members of the AIDS subpopulation. Hence, lost life years due to mortality occur further in the future. This tendency appears to have been outweighed by the difference in the number of *Cryptosporidium*-related deaths.

The total population cost-effectiveness ratios for calculated using a 3% and 5% discount rate differ modestly (\$1,719 per QALY for the 5% discount rate vs. \$1,532 for the 3% discount rate). This finding indicates that the discount rate does not substantially affect the results of this analysis. The difference can be traced to the AIDS subpopulation as the difference between the general population cost-effectiveness ratios for the two discount rates is small (\$4,134 for a 3% discount rate vs. \$4,235 for a 5% discount rate).